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Human Health and Ecological Risk Assessment (HHERA)

Norfolk Island Airport

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Document Information

Human Health and Ecological Risk Assessment (HHERA),
Norfolk Island Airport

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Senversa acknowledges the traditional custodians of the land on which this work was created and pay our respect to Elders past and present.

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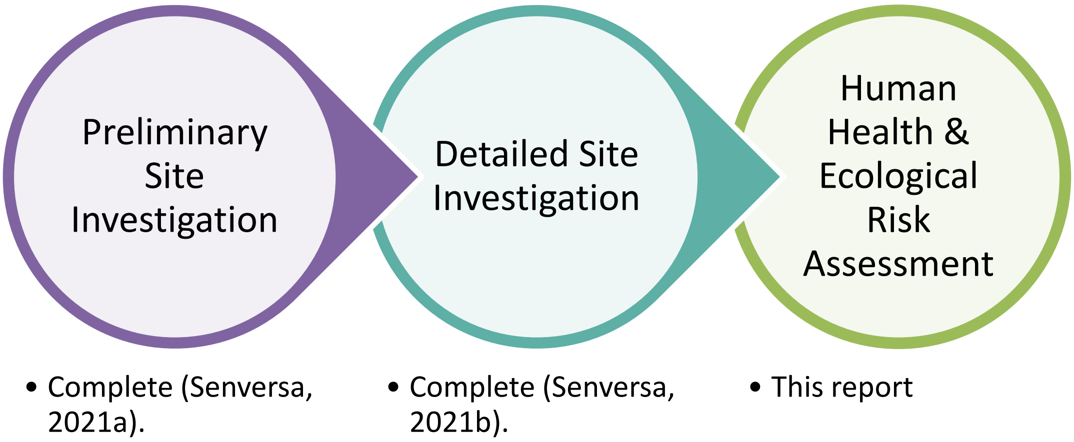
Executive Summary

Background to the Human Health and Ecological Risk Assessment

Senversa was engaged by the Department of Infrastructure, Transport, Cities and Regional Development (DITCRD) now the Department for Infrastructure, Transport, Regional Development and Communications (DITRDC) to prepare a Detailed Environmental Investigation of per- and poly-fluoroalkyl substances (PFAS) site conditions at Norfolk Island Airport (the site) and surrounding catchments.

The PFAS detailed environmental investigation process consists of three main steps:



The Preliminary Site Investigation (PSI) and Detailed Site Investigation (DSI) identified PFAS sources, contaminant transport pathways and receptors potentially exposed to PFAS, and presented the findings of the initial, targeted investigation into the nature and extent of PFAS at the Norfolk Island Airport and surrounding catchments.

Based on the results of the PSI and DSI, It was determined that:

- Risks are low and acceptable for many of the ways in which people might be exposed to PFAS in the environment. This includes drinking water; drinking water is often (on other sites) the most significant PFAS exposure pathway, but on Norfolk Island, concentrations of PFAS in the water people currently drink has been shown to be below the HBGV, and the risks are therefore assessed to be low.
- There were a number of pathways for which the risks were assessed to be low and acceptable in the DSI because management measures have been put in place. Further assessment of currently managed pathways is outside of the scope of the HHERA; however, ongoing management of these pathways is required. A PFAS Management Plan will be prepared, which will detail the ongoing management which is required for each identified source area, and for identified potential exposure pathways (including pathways which are currently managed).

- A small number of pathways were identified for which further assessment is required to better assess potential risks. This included pathways where conservative screening levels were exceeded, or where no relevant screening levels were identified. Senversa recommended that a Human Health and Ecological Risk Assessment (HHERA) be completed to assess the risks associated with these pathways.

Scope of the Human Health and Ecological Risk Assessment

The scope of the risk assessment is to assess the potential risks associated with those pathways for which risks were not excluded in the DSI. These pathways are as follows:

Consumers of livestock products

- Consumption of cattle products (potentially including beef, tallow, offal and bones) from cattle watered with water containing PFAS, or fed grass containing PFAS.
- The risks to other livestock and livestock health will also be assessed.

Consumers of produce (fruit and vegetables)

- Consumption of fruit and vegetables irrigated with water containing PFAS.
- It is noted that PFAS was not detected in sampled fruit and vegetables watered with PFAS impacted water, so risks are likely to be low, but will be further assessed on additional properties where concentrations in irrigation water were lower, but where produce was not sampled.

Consumers of chicken eggs

- Consumers of chicken eggs where chickens are watered with water containing PFAS.
- It is noted that PFAS concentrations in a sampled chicken egg were measured to be below the acceptable levels (FSANZ tigger), however data is limited and the uncertainties associated with this limited data will be further assessed in the HHERA.
- There is only one known property where PFAS impacted water is used to raise chickens; risks will therefore be assessed for this property.

Firefighters

- Exposure to PFAS impacted water during systems testing, training and firefighting.

On-airport workers (intrusive workers and airport workers)

- Exposure to PFAS in soils and dust.
- Concentrations in soil are below the screening level for commercial/industrial workers (HIL-D), but this pathway will be further assessed in the HHERA as the HIL-D is not directly applicable to intrusive workers or workers who work most of the day outdoors.

Off-site residents (e.g. farmers) or recreational users of creeks

- Incidental contact with surface water in creeks during work or recreation.

Terrestrial ecological receptors

- Exposure to PFAS impacted soil, groundwater and sediments (while creeks are dry), or via bioaccumulation of PFAS through the food web.

Freshwater aquatic ecological receptors

- Exposure to PFAS impacted surface water and sediments in on-island creeks, or via bioaccumulation of PFAS through the food web from these creeks.
- Risks to the marine environment (both direct and indirect exposure) are assessed to be negligible in accordance with the conclusions of the DSI.

This HHERA has been prepared to assess current potential risks posed by detected PFAS that are the result of the historical use of legacy AFFF (aqueous film-forming foams, which contained PFAS) on Norfolk Island Airport. The HHERA considers the current concentrations of PFAS in the environment, and the current ways in which exposure occurs to assess whether there are potential risks to people and the environment. The results of the HHERA will be used to determine whether further investigation, management and/or remediation is required, to be undertaken as part of the PFAS Management Plan.

Outcomes of the Human Health and Ecological Risk Assessment

Pathways assessed to pose negligible risk

For the following pathways, risks are assessed to be negligible, and further assessment is not required:

Livestock

- Home consumption or public consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment.
- Home consumption of public consumption of cattle products, where cattle are fed with grass cut from the airport.
- Livestock health (across the island).

Consumers of produce (fruit and vegetables)

- Consumption of home produce (fruit/vegetables) grown within the Mission Creek catchment (at the one property where this currently occurs).
- Consumption of home produce (fruit/vegetables) grown outside the Mission Creek catchment.

Consumers of chicken eggs

- Consumption of chicken eggs where chickens drink water sourced from outside Mission Creek catchment.

Firefighters

- Systems testing, training and firefighting activities completed by firefighters using water sourced from the Airport Bore.

On-airport workers

- Incidential soil and dust exposure by intrusive workers.
- Incidental soil and dist exposure by airport workers.

Off-site residents (e.g. farmers) or recreational users of creeks

- Incidental contact with surface water in creeks during work or recreation.

Terrestrial ecological receptors

- Exposure to PFAS impacted soil, groundwater and sediments (while creeks are dry), or via bioaccumulation of PFAS through the food web.

Aquatic ecological receptors

- Direct exposure of aquatic species to water in creeks other than Mission Creek.
- Risks to the marine environment (both direct and indirect exposure) are also assessed to be negligible (in accordance with the conclusions of the DSI).

Pathways for which further assessment or management required

Livestock

- Home consumption or public consumption of cattle products where cattle drink water sourced from Mission Creek.
  - Risks to public consumers are assessed to be generally **low and acceptable**. Nonetheless, there are a number of uncertainties in the assessment, and therefore further assessment and/or management is recommended.
  - It is emphasised that there are no regulatory restrictions with respect to PFAS in livestock products (including cattle products) and that, currently, there are no regulated maximum limits for PFAS in any foods in Australia or overseas but research is ongoing.

Consumers of chicken eggs

- Consumption of chicken eggs where chickens drink water sourced from Mission Creek.
  - Risks are low and acceptable based on the limited available data. Given the uncertainties associated with the limited data set, further assessment and/or management is recommended.

Aquatic ecological receptors

- Direct exposure of aquatic species to water in Mission Creek.
- Indirect exposure to birds which may consume aquatic species as part of their diet (both in Mission Creek and other creeks) .

A strategy for managing the risks associated with the identified PFAS impacts on the airport and across the island, including specific strategies for further assessment and/or management for the pathways detailed above, should be developed. These strategies should be detailed within the PFAS Management Plan.

Data Gaps

The HHERA has identified a number of areas where risks are unlikely to be elevated, but additional data is required to confirm potential risks:

Grass concentrations in Mission Creek

While the risks to consumers of produce where the cattle have access to grass within Mission Creek are assessed to be low and acceptable, it is acknowledged that the available data regarding PFAS in grass within the Mission Creek bed is very limited, and that further sampling would therefore support the assessment.

The requirement for further assessment/management of this pathway will be further assessed as part of the PFAS Management Plan.

Assessment of risk to consumers of pork products

There is limited literature data on which to estimate screening levels for pigs. On this basis, when coupled with the limited information regarding where pigs might be kept and stock watering sources for these animals, further assessment has not been undertaken at this stage. The following are noted:

- Water and Land use surveys have not provided any indication that pigs are kept in the Mission Creek catchment. This pathway is assessed as inactive.
- Risks from consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment are assessed to be low and acceptable (based on comparison to screening levels which assume high consumption rates). As noted in the HHERA, the keeping of pigs is limited on island and consumption rates are likely to be generally lower than other livestock product types (e.g. cattle). On this basis, it is unlikely that elevated risks would be associated with the consumption of pork and other pig products where pigs drink water sourced from outside Mission Creek catchment. Notwithstanding this, risks cannot be fully excluded without additional information and/or assessment.

This is noted as a data gap; the requirement for further assessment/management of this pathway should be assessed as part of the PFAS Management Plan.

Future changes in conditions

The HHERA assesses the current risks associated with the currently identified concentrations of PFAS in the environment; and the current ways in which exposure occurs.

There is insufficient data to fully establish trends in water concentrations. Further monitoring should be conducted as part of the PFAS Management Plan to determine the long-term trend in water concentrations. The PFAS Management Plan should also detail the strategy for assessing ongoing monitoring results, noting that changes in concentration could result in changes to the risk profile presented in this HHERA.

In addition, it is noted that the HHERA is based on the current land uses at the time of the PSI and DSI completed by Senversa. If land uses were to change in the future, it is noted that the risk profile may change. The PFAS Management Plan should therefore also detail the strategy for assessing changes to the risk profile in the event of future land use changes.

Contents

List of Acronyms

Acronym	Definition
AFFF	Aqueous Film Forming Foams
ANZG	Australia and New Zealand Guidelines
ATSDR	Agency for Toxic Substances and Disease Registry
COPC	Contaminant of potential concern
CSM	Conceptual site model
DITRDC	Department for Infrastructure, Transport, Regional Development and Communications
DSI	Detailed Site Investigation
EIL	Ecological investigation level
EPA	Environment Protection Authority
EPBC	Environment Protection and Biodiversity Conservation
ESL	Ecological screening level
HBGV	Health based guidance value
HHERA	Human Health and Ecological Risk Assessment
HIL	Health investigation level
HSL	Health screening level
LOR	Limit of reporting
NEMP	National Environmental Management Plan
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure

Acronym	Definition
NHMRC	National Health and Medical Research Council
NIRC	Norfolk Island Regional Council
NOAEL	No-observed-adverse-effect-level
NOEC	No Observed Effect Concentration
PEF	Particulate emission factor
PFAS	Per- and poly-fluoroalkyl substances
PFBS	Perfluorobutane sulfonic acid
PFCA	Perfluorocarboxylic acid
PFHpS	Perfluoroheptane sulfonate
PFHxA	Perfluorohexanoic acid
PFHxS	Perfluorohexane sulfonate
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PFPeS	Perfluoropentane sulfonate
PFSA	Perfluoroalkyl sulfonates
POP	Persistent organic pollutant
PPE	Personal protective equipment
PSI	Preliminary Site Investigation
SSD	Species Sensitivity Distribution
TDI	Tolerable daily intake
TMI	Tolerable monthly intake

Acronym	Definition
TRV	Toxicity reference values
TWI	Tolerable weekly intake
UCL	Upper confidence limit
USEPA	United States Environment Protection Agency
WWTP	Waste water treatment plant

1.0 Introduction and Objectives

1.1 Introduction

Senversa was engaged by the Department of Infrastructure, Transport, Cities and Regional Development (DITCRD) now the Department for Infrastructure, Transport, Regional Development and Communications (DITRDC) to prepare a Detailed Environmental Investigation of per- and poly-fluoroalkyl substances (PFAS) site conditions at Norfolk Island Airport (the site) and surrounding catchments.

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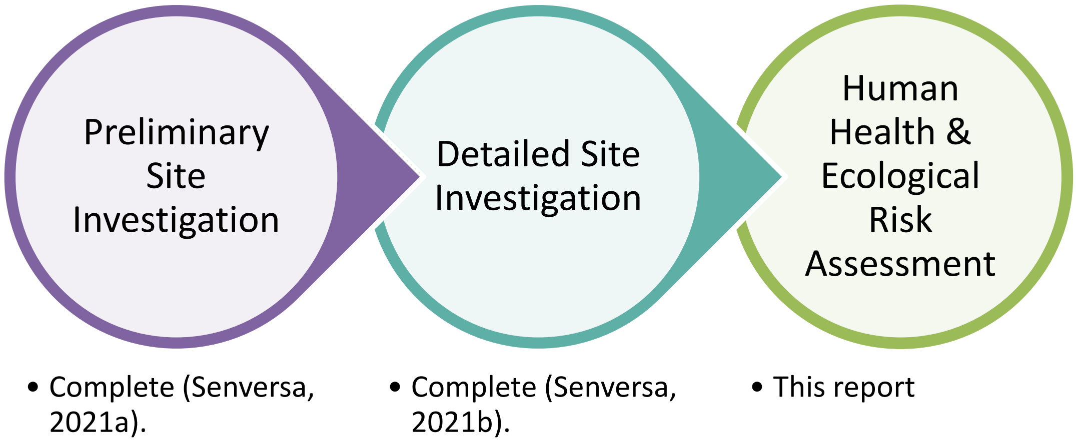


The Preliminary Site Investigation (PSI) and Detailed Site Investigation (DSI) identified PFAS sources, contaminant transport pathways and receptors potentially exposed to PFAS, and presented the findings of the initial, targeted investigation into the nature and extent of PFAS at the Norfolk Island Airport and surrounding catchments.

A component of the investigations was to determine the need for completion of a Human Health and Ecological Risk Assessment (HHERA) to assess potential risks posed by detectable PFAS that are the result of activities on Norfolk Island Airport. Qualitative assessment and comparison to relevant Tier 1 screening levels indicated that reported PFAS concentrations in some locations / environmental media have the potential to pose a risk to human health or the environment. Based on these results, Senversa recommended that the HHERA process be commenced.

1.2 Background

PFAS investigations were initiated after a CSIRO-led assessment of water resources identified elevated levels of PFAS in the Mission Creek water catchment in December 2019. The location of the airport and the Mission Creek water catchment with reference to the wider Norfolk Island is shown on **Figure 1-1** below.

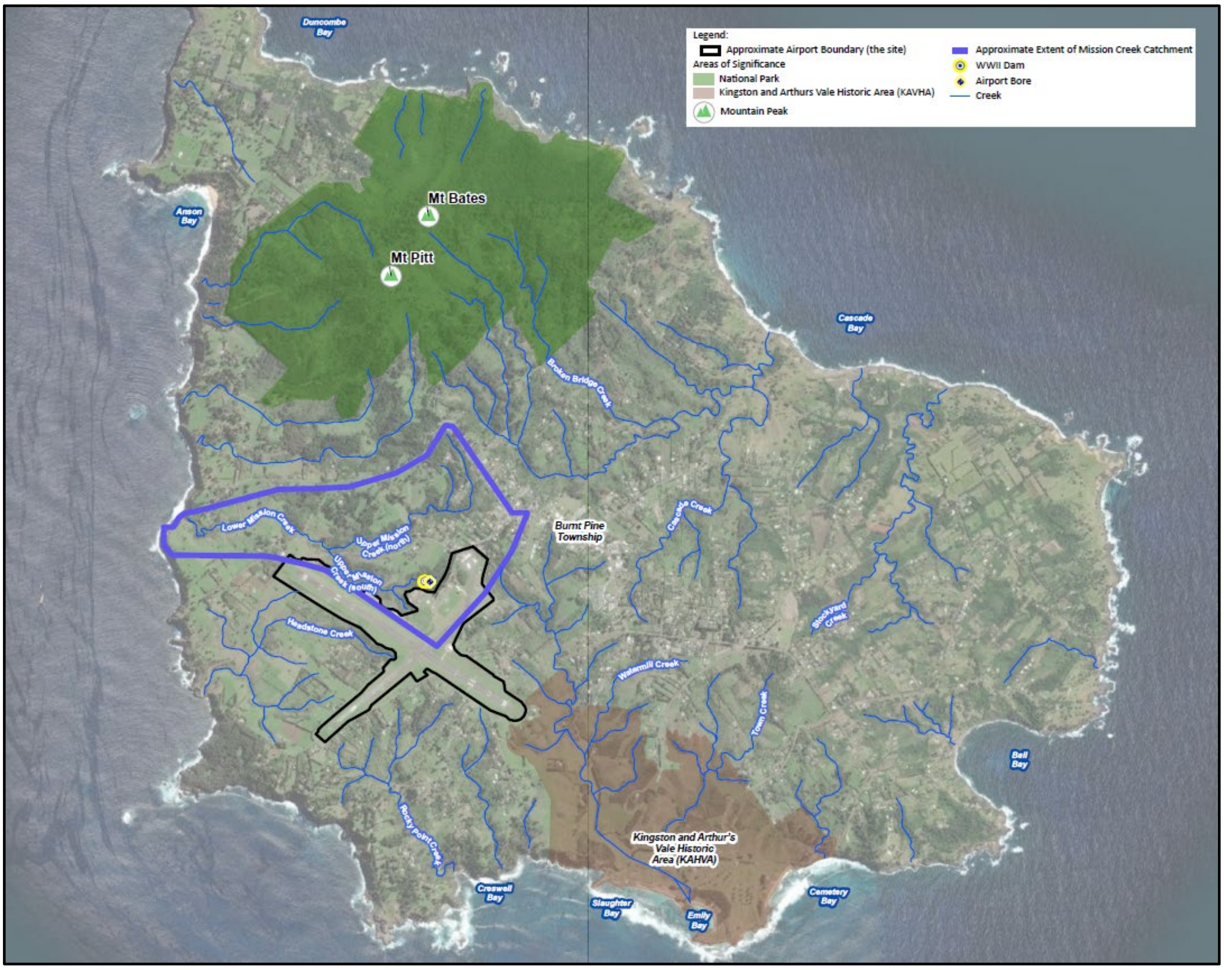


Figure 1-1: Site Location and Key Norfolk Island Features

1.3 HHERA objectives

1.3.1 Overall objectives

This HHERA has been prepared to assess current potential risks posed by detected PFAS that are the result of historical activities on Norfolk Island Airport. The results of the HHERA will be used to determine whether further investigation, management and/or remediation is required.

The overall objective of the HHERA is to assess risk to human health and the environment due to the presence of contaminants associated with historical use of legacy AFFF (aqueous film-forming foams, which contained PFAS) on Norfolk Island Airport.

1.3.2 Tiered risk assessment approach

In accordance with the NEPM, a tiered approach to the assessment of risk is being used to understand the risk to human health and the environment.

A Tier 1 risk assessment is a risk-based analysis comparing site data with generic investigation and screening levels for various land uses to determine the need for further assessment or development of an appropriate management strategy (NEPC, 2013).

A Tier 2 assessment is a site-specific assessment where preliminary screening risk assessment performed as part of the Detailed Site Investigation (DSI) indicates that contaminants are present at concentrations above relevant Tier 1 screening levels and/or where no suitable Tier 1 screening levels are available. It is noted that the Tier 1 screening values referenced are not always applicable to all potential exposure pathways relevant to each environmental medium, thus do not necessarily provide an indication of the risk posed to human health or the environment.

The HHERA will comprise a quantitative (Tier 2) assessment of risk.

1.4 Exposure scenarios considered in HHERA

1.4.1 Assessment of current exposure

The HHERA is intended to assess risks posed by PFAS contaminants associated with historical use of legacy AFFF on Norfolk Island Airport.

The presence of PFAS impacts identified in the DSI is attributed to the historical use of fire-fighting foams (aqueous film-forming foams, referred to as AFFF) which contained PFAS, with on-airport training activities identified as the primary source for the majority of the identified impacts. It is emphasised that the use of AFFF containing PFAS as an active ingredient during on-airport training has ceased, meaning the major historical source for PFAS to enter the environment has ceased. Works are underway to remove unused stocks of PFAS-containing AFFF from the island, and to clean the fire trucks in which PFAS-containing AFFF was historically used. The identified PFAS within the environment is related to historical (not current) use of AFFF containing PFAS.

This HHERA assesses the current risks associated with this historical contamination, considering the current concentrations of PFAS in the environment, and the current ways in which exposure occurs. A number of management measures have been implemented to limit the potential ways in which people might be exposed to the PFAS identified in the environment (e.g. through restricting the use of water in which PFAS has been identified). This HHERA assumes that current management measures will remain in place. A summary of the management measured currently in place is provided in **Section 1.4.2** below.

The assessment will focus on current land uses. There is the potential for land use changes to result in other pathways becoming relevant, e.g. changing agricultural uses, etc. The HHERA has commented, where practicable, on the potential for changing land uses to impact upon the risk profile (see **Section 11.5**).

1.4.2 Management of Identified PFAS Impacts

Following the identification of PFAS in groundwater in late 2019, DITRDC have undertaken a number of management actions aimed at reducing the potential for exposure to the identified PFAS within the on-island environment both on-airport and off-airport, focussing on managing the exposure to PFAS identified in water used (or potentially used) for drinking water or domestic water supply.

These measures have been undertaken incrementally as information has become available on the nature and extent of PFAS on Norfolk Island:

Use of water from the airport bore

- Following the identification of PFAS in the airport bore, residents on Norfolk Island were advised on 14 January 2020 to discontinue use of water from the airport bore. Locks were also placed on the road standpipe (connected to the airport bore) in February 2020 where water had been historically collected for a variety of uses.
- DITCRD has commissioned ECT2 to provide a point of use treatment system (POETS) at the new fire station to remove PFAS and allow water extracted from the airport bore to be safely used for firefighting. Treated water will be tested and provided PFAS levels in the treated water are within the NEMP health-based guidance value (HBGV) for drinking water, the intention is to use the treated water within the fire trucks. The intended use of treated water in the fire trucks is expected to remain in place for the medium term as the Island progresses to becoming reliant on rain water only.

Drinking water and domestic water advisory measures

- Media releases (including includes six fact sheets and five media releases issued by DITRDC) have provided advice not to use water from the following sources for drinking or domestic use:
  - Groundwater from within the Mission Creek catchment.
  - Surface water extracted from Mission Creek or Watermill Creek.
- It is noted that none of these sources have been identified to currently be used for drinking water or domestic use.
- These water sources are variously utilised for other uses (e.g. stock watering, irrigation). No advice has been issued for these other uses; the risks associated with non-domestic uses is the subject of further assessment in the HHERA.

Drinking water at the fire station and other on-airport buildings

- PFAS was identified above the HBGV in domestic water at the fire station and airport maintenance sheds on the airport, assessed to be related to historic use of airport bore water for domestic supply to these buildings.
- Alternate water for domestic use has been supplied to these buildings as well as the airport terminal toilets, on-airport council buildings and the BOM office (where detectable PFAS below the HBGV was reported).
- Two large rainwater tanks have been recently installed adjacent to the fire station. The tanks will supply potable water for use inside the fire station with works proposed to be completed in early 2022.
- New rainwater tanks connected to the roof of the airport terminal and ancillary buildings have been purchased and are currently in the process of being installed.

Drinking water supply at the hospital

- PFAS was identified above the HBGV at the point of use (kitchen tap) within the hospital.
- The hospital water supply at the time was from rainwater tanks, which did not contain PFAS above the HBGV.
- The source was traced to the filtration system previously used by the hospital, likely related to to historical supply of PFAS-containing water (e.g. from the airport bore) to the hospital, which resulted in residual PFAS within the filtration system, which subsequently leached into water during filtration (even after switching water supply).
- The filtration system at the hospital has been fully replaced and testing has indicated that it is no longer a source for PFAS into the hospital drinking water supply. Water sampling from hospital taps completed in February 2021 (following replacement of the filtration system in March 2020) indicated PFAS concentrations to be below the HBGV.

Drinking water supply at the council works depot

- PFAS was identified above the HBGV at the point of use (kitchen tap) and one tank within the works depot, assessed to be likely related to the works depot historically utilising airport bore water for domestic supply.
- Alternate water has been supplied to these buildings for domestic use since February 2020.

Drinking water at private residences

- The works completed in the DSI and PSI included investigations of private domestic water supplies (e.g. rainwater tanks, domestic taps) to identify whether PFAS was present above the HBGV.
- While these investigations were proceeding, alternate water supplies were offered to residences within the Mission Creek catchment as a precautionary measure.
- The investigations indicated that these private water supplies were unimpacted with PFAS above the HBGV. However, to date, DITRDC have continued to supply alternative water sources to these residents.

Public toilets

- PFAS has been identified in the water supply at some public toilets, assessed to be likely related to the former carting of water from the airport bore for use in the public toilets.
- Signs have been placed in the toilets indicating the water is not suitable for drinking.

The management measures detailed above are assessed to be effective in currently managing the potential risks associated with PFAS in drinking and domestic water supplies. As discussed in **Section 1.4.1**, the focus of the HHERA is on the assessment of current risks based on current exposure pathways. Further assessment of the drinking water and domestic water exposure pathways which are currently managed by these measures is therefore outside of the scope of the HHERA.

While these pathways are not assessed further in the HHERA, there is, however, a requirement for the management measures detailed above to continue in order to manage the future exposure to PFAS in drinking water and domestic water supplies, until such a time where they are assessed to be no longer required. Specifically, where PFAS is present above HBGVs in water, this water should not be used for drinking or domestic use. The ongoing implementation of these management measures, together with associated controls, monitoring and assessment of efficacy as required, should be captured within the PFAS Management Plan.

In addition to these measures focussed on managing the exposure to PFAS identified in water, a number of source management activities have also been undertaken, or are currently being undertaken. These works focus on the reduction of PFAS mass on-island, and will reduce the potential for further PFAS to enter the environment in the future:

Phasing out of use of AFFF containing PFAS

- Fire training commenced on the island in 1942.
- Legacy AFFF (containing PFAS as an active ingredient) used on island includes 3M lightwater and Tyco Ansulite. 3M lightwater is understood to have been introduced to the island in the early 1980s and was used for approximately 20 years until the island changed to AFFF Tyco Ansulite in 2004.
- While some fire trucks still contain Ansulite, which is only used in emergency situations, Legacy AFFF (containing PFAS as an active ingredient) has not been used for training since 2015.
- Historic on-airport training activities with AFFF containing PFAS were identified in the DSI as the primary source for the majority of the identified PFAS impacts; as training with AFFF containing PFAS no longer occurs, this source for PFAS entering the environment has ceased.

Fire-truck cleaning and decontamination programme

- NIFS owns 4 firefighting trucks which have used legacy AFFF (with PFAS as active ingredients) and still contain legacy AFFF in their concentrate tanks.
- DITRDC is organising to have the trucks cleaned and have the legacy AFFF replaced with new AFFF (not containing PFAS as an active ingredient). Additionally, the Department is organising to ensure the water used to re-fill the fire trucks is treated to ensure PFAS levels are within the NEMP HBGV for drinking water.
- DITRDC has engaged GHD to establish a cleaning hub at the fire station to clean the fire-fighting vehicles. This will be undertaken following the installation of required infrastructure (currently underway).
- Legacy AFFF will be removed from the fire trucks and replaced with new AFFF (not containing PFAS as an active ingredient).
- The wash water captured during truck cleaning will be treated using a point of use treatment (POET) filter to remove PFAS, and tested. Provided PFAS levels are within the NEMP HBGV for drinking water the water will be stored for use in the fire trucks.
- All legacy AFFF will then be removed from the island to be disposed on the mainland.

The implementation of these source management measures should also be captured and assessed within the PFAS Management Plan.

1.4.3 Pathways requiring assessment

One of the key outcomes of the DSI was the development of a conceptual site model (CSM) detailing the various “pollutant linkages” via which people and environmental receptors could be potentially exposed to PFAS. For each of these pollutant linkages, conclusions were drawn regarding whether there is potentially elevated exposure, and if further risk assessment is required.

It was determined that risks are low and acceptable for many of the ways in which people might be exposed to PFAS in the environment. This includes drinking water; drinking water is often (on other sites) the most significant PFAS exposure pathway, but on Norfolk Island, concentrations of PFAS in the water people currently drink has been shown to be below the HBGV, and the risks are therefore assessed to be low.

Because the screening levels used in the DSI are very conservative, where concentrations are below the screening levels, exposure risks are assessed to be negligible, and further assessment of the potential risks via these pathways is assessed as not being required.

There were a number of pathways for which the risks were assessed to be low and acceptable in the DSI because management measures have been put in place, as discussed in **Section 1.4.2**. Further assessment of currently managed pathways is outside of the scope of the HHERA; however, ongoing management of these pathways is required and should be undertaken as part of the PFAS Management Plan.

A small number of pathways were identified for which further assessment is required to better assess potential risks. Those pathways requiring further assessment where unacceptable risks cannot be excluded due to exceedance of adopted screening criteria (or because no relevant screening criteria are available), are the following (in no particular order):

Consumers of livestock products

- Consumption of cattle products (potentially including beef, tallow, offal and bones) from cattle watered with water containing PFAS, or fed grass containing PFAS.
- The risks to other livestock and livestock health will also be assessed

Consumers of produce (fruit and vegetables)

- Consumption of fruit and vegetables irrigated with water containing PFAS
- It is noted that PFAS was not detected in sampled fruit and vegetables watered with PFAS impacted water, so risks are likely to be low, but will be further assessed on additional properties where concentrations in irrigation water were lower, but where produce was not sampled.

Consumers of chicken eggs

- Consumers of chicken eggs where chickens are watered with water containing PFAS
- It is noted that PFAS concentrations in a sampled chicken egg were measured to be below the acceptable levels (FSANZ tigger), however data is limited and the uncertainties associated with this limited data will be further assessed in the HHERA
- There is only one known property where PFAS impacted water is used to raise chickens; risks will therefore be assessed for this property

Firefighters

- Exposure to PFAS impacted water during systems testing, training and firefighting

On-airport workers (intrusive workers and airport workers)

- Exposure to PFAS in soils and dust
- Concentrations in soil are below the screening level for commercial/industrial workers (HIL-D), but this pathway will be further assessed in the HHERA as the HIL-D is not directly applicable to intrusive workers or workers who work most of the day outdoors

Off-site residents (e.g. farmers) or recreational users of creeks

- Incidental contact with surface water in creeks during work or recreation

Terrestrial ecological receptors

- Exposure to PFAS impacted soil, groundwater and sediments (while creeks are dry), or via bioaccumulation of PFAS through the food web.

Freshwater aquatic ecological receptors

- Exposure to PFAS impacted surface water and sediments in on-island creeks, or via bioaccumulation of PFAS through the food web from these creeks.
- Risks to the marine environment (both direct and indirect exposure) are assessed to be negligible in accordance with the conclusions of the DSI

2.0 Risk Assessment Framework

2.1 Human Health Risk Assessment

The human health component of the risk assessment will be conducted in accordance with relevant Australian guidance. The framework and methodology for human health risk assessment (HHRA) in Australia is specified in the following documents:

- *Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks From Environmental Hazards* (enHealth, 2012).
- *National Environment Protection (Assessment of Site Contamination) Measure 1999* (as amended 2013), *Schedule B4, Guideline on Site-specific Human Health Risk Assessment Methodology* (NEPC, 2013).

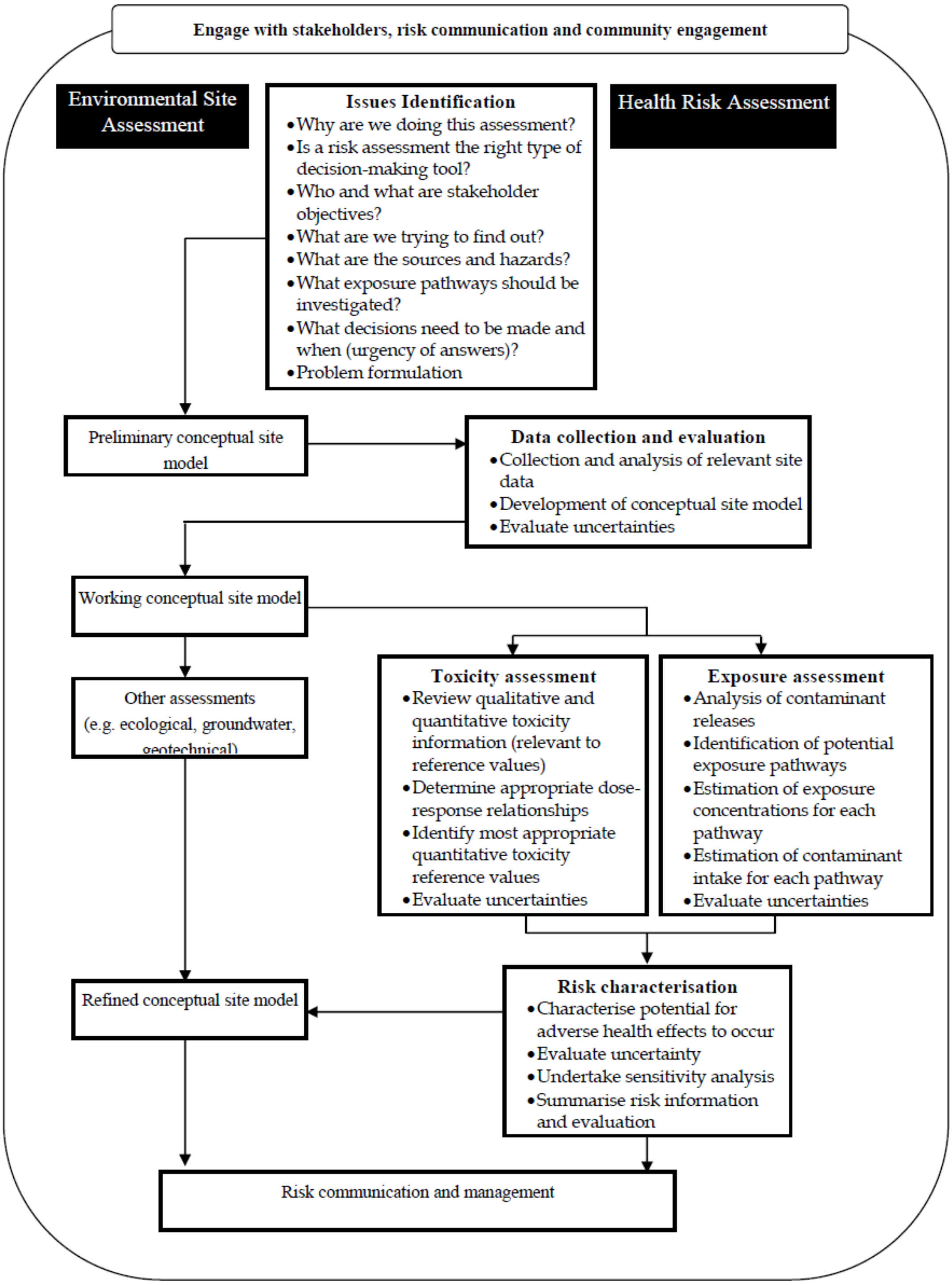
In addition, reference has been made to the following key guidance specifically relevant to undertaking PFAS risk assessment:

- *PFAS National Environmental Management Plan Version 2.0 (PFAS NEMP 2.0),* developed by the Heads of EPA (HEPA) (HEPA, 2020).

In accordance with the above documents, the HHRA process comprises the following elements:

- **Issue Identification**, which includes identification of the objectives of the risk assessment, the problems that the risk assessment needs to address, and the risk management decisions that need to be made based on the HHRA. A key component of this stage is development of preliminary conceptual model describing the sources, receptors and exposure pathways that will be evaluated.
- **Data Collection and Evaluation,** which includes review of available data and information, and identification of the contaminants of potential concern (COPC) requiring detailed quantitative consideration in the risk assessment. COPC are usually selected for detailed assessment based on comparison to published health-based guidance values which are based on conservative exposure assumptions and designed to be protective of most exposed populations. These are commonly referred to as 'Tier 1' screening levels.
- **Toxicity Assessment**, which includes evaluation of both qualitative and quantitative information about the toxicity of identified COPC, in order to describe the nature and incidence of adverse health effects which could occur in humans at different exposure levels, and to identify relevant toxicity reference values (TRVs), which are either a measure of the tolerable daily intake that will cause no adverse effect over a lifetime of exposure, or an estimate of the excess lifetime risk of cancer associated with a given chemical dose. Adopted TRVs will be those derived by FSANZ (FSANZ, 2017) and incorporated into the PFAS NEMP 2.0 (HEPA, 2020).
- **Exposure Assessment**, which includes identification of exposed human populations (receptors) and the pathways via which they may be exposed to COPC, and derivation of quantitative estimates of exposure point concentrations and contaminant intakes for each pathway. The exposure assessment will also consider (where relevant) potential background exposures to PFAS.
- **Risk Characterisation**, which involves comparison of estimated exposure levels to relevant toxicity (dose-response) criteria to estimate the potential incidence and nature of adverse health effects to human receptors. The risk characterisation stage also includes interpretation of risk estimates in the context of the uncertainties and assumptions of the risk assessment process.

The framework is also depicted in the following flowchart (extracted from NEPC, 2013).



The HHERA will use this framework to assess the human health exposure pathways described in **Section 1.4.3.**

For clarity, the risk assessment will assess each of the identified pathways in turn; **Sections 5.0** to **Section 10.0** present the individual assessment completed for each of these pathways. **Section 11.0** discusses the potential impact on someone's exposure to PFAS if they are exposed via multiple of these pathways.

For each of these assessed pathways, the same toxicity information is used. This toxicity information, including discussion of which PFAS compounds have been considered in the assessment, is provided in **Section 4.0**.

2.2 Ecological Risk Assessment

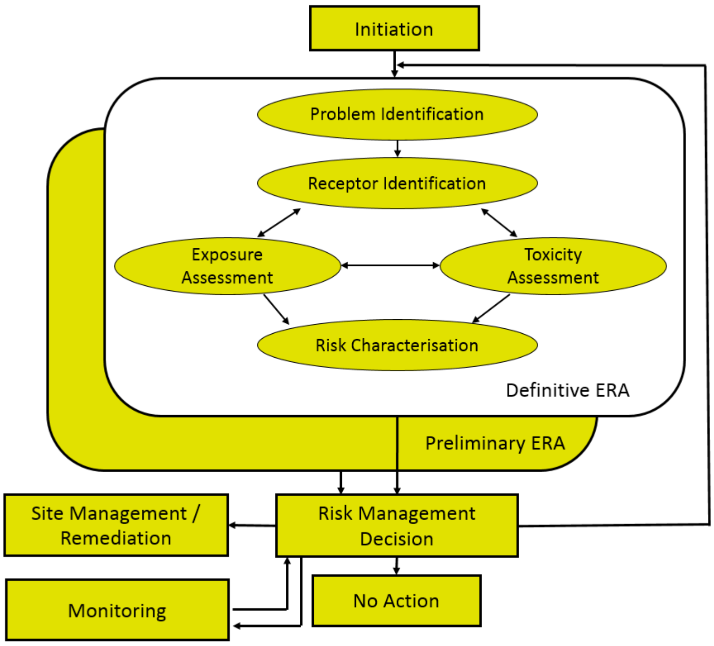
The ecological component of the risk assessment will be conducted in accordance with relevant Australian guidance. The framework and methodology for ecological risk assessment (ERA) in Australia, together with key guidance around assessment approaches is specified primarily in the following documents:

- *National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013), Schedule B5a, Guideline on Ecological Risk Assessment* (NEPC, 2013).
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018).
- *PFAS National Environmental Management Plan Version 2.0 (PFAS NEMP 2.0),* developed by the Heads of EPA (HEPA) (HEPA, 2020).

While the NEPM (NEPC, 2013) is generally focused on assessment of risk to terrestrial ecological systems due to soil contamination, the guidance provided does provide a clear overview of the ERA process which is applicable to assessment of both terrestrial and aquatic ecosystems. The framework provided within the NEPM indicates that an ERA should consist of the following basic components:

- Problem identification – scoping phase to establish objectives and identify relevant data for the assessment;
- Receptor identification – identifies species, communities and ecosystem processes that require protection, and considers the level of protection that should be applied;
- Exposure assessment – characterises the potential exposure pathways, exposure duration, exposure concentrations and intakes;
- Toxicity assessment – identification of appropriate toxicity values for the COPC identified; and
- Risk characterisation – considers the calculated intakes relative to identified toxicity values to assess whether a risk may be posed to the identified receptors.

The following diagram illustrates the purpose and key activities associated with the ERA and how each of these tasks fits into the overall assessment of risks.



The HHERA will use this framework to assess the ecological exposure pathways described in **Section 1.4.3**

Section 11.0 presents the assessment undertaken for terrestrial ecological receptors. **Section 12.0** presents the assessment undertaken for aquatic ecological receptors.

3.0 Data Evaluation

3.1 Background

A preliminary site investigation (PSI) with targeted sampling of surficial soil was undertaken by Senversa in January 2020, which comprised collection and analysis of 76 soil, 11 sediment, 11 surface water, 1 water and 21 groundwater samples collected from onsite (airport) and offsite (wider Norfolk Island) locations. The Detailed Site Investigation (DSI) completed in March 2021 included grid based surficial assessment of PFAS source areas (**DSI Figure 5**); targeted deeper soils assessment (**DSI Figure 5**); assessment of the wastewater treatment plant (**DSI Figure 5**); sequential paired sediment and surface water sampling along Mission and Watermill Creeks (**DSI Figures 2, 6** and **7**), further confirmatory sampling of on and off-site drinking water sources and assessment of produce in the Mission Creek Catchment (**DSI Figure 4**). The DSI comprised analysis of 235 soil, 40 sediment, 26 surface water, 5 groundwater, 41 water, 22 grass and 7 biota (produce) samples collected from onsite (airport) and offsite (wider Norfolk Island) locations.

The PSI and DSI works identified 17 potential and confirmed PFAS source areas onsite (Airport) and off site (wider Norfolk Island). Six PFAS primary source areas were identified within the Airport, with Former Fire Station and Foam Shed and Former Flushing Out Area considered to represent the main sources of PFAS identified within Mission Creek surface water. All six sources were associated with the training, storage and / or maintenance of fire trucks that historically used Legacy AFFF. The other PFAS source areas (considered to have a lower potential for risk) identified outside of the Airport within the PSI are inferred to be present and no additional PFAS Source Areas were identified during completion of this DSI.

The analytical results for all media sampled as part of the PSI and DSI are presented within **Tables 1 to 9**.

3.2 Sampling and Rationale

A summary and rationale of the sampling and investigations undertaken as part of the PSI and DSI onsite (airport) and offsite (wider Norfolk Island) include the following:

- Point of use (drinking water) sampling was undertaken at private properties and public facilities to assess drinking water exposure and to confirm the suitability of the water supply.
- Public toilets tap water was sampled due to historical “Airport Bore” use.
- Soil sampling was undertaken in both the PSI and DSI, where the sampling was to:
  - Investigate potential onsite source zones identified in the site history review (PSI) and off-site areas suspected to potentially be PFAS impacted based on water use, proximity to source areas and the local drainage features.
  - Investigate areas that were not able to be accessed or were not assessed during the PSI; the current drill ground, the WWTP, the common oval and a private property where contaminated groundwater or surface water has been used for irrigation or stock watering purposes. Refer to **Figure 5** for sampling locations on the Airport and **Figure 4** for the private property sampling.
  - Delineate locations where elevated PFAS was identified in the PSI. Refer to **Figure 5** for delineation sampling locations.
  - Further investigate areas where soils were considered to have a higher potential to act as an ongoing source. Refer to **Figure 5** for sampling locations.

- Surface water and sediment sampling was undertaken in all catchments to investigate the extent of PFAS in surface water bodies off-site, which was required to assess risks to potentially sensitive receptors (refer **Figure 6** for sediment sampling locations in Mission Creek and **Figures 2** and **7** for surface water sampling locations across the island). Sampling included:
  - Sampling surface water and sediment in drainage lines entering Mission, Headstone and Watermill creek from the site (airport).
  - Sampling of surface water and sediment in Mission Creek every 200 m (downgradient of identified source zones)
  - Sampling up and down gradient in both Headstone and Watermill Creek.
  - Sampling saline sediments at the mouth of Mission, Headstone and Watermill Creek (not completed for Mission Creek and Headstone)
  - Surface water and sediment sampling of drainage lines in the WWTP area.
- Sampling of grass and biota (i.e. eggs, fruit, vegetables) in Mission Creek Catchment in areas where contaminated groundwater and surface water are currently, or have historically been used to water market gardens, poultry and cattle. Biota samples collected with the Mission Creek Catchment were paired with surface water and sediment samples, where there was potential for cattle to graze. Biota (grass) sampling was also undertaken across the airport where grass clippings are understood to be fed to cattle.
- Groundwater sampling undertaken on and offsite during the PSI and DSI, particularly within the Mission Creek catchment to assess water sources (stock, irrigation) where there was potential for contamination.

3.3 Validation of Sampling and Data

The data validation process involved the checking of analytical procedure compliance with acceptance criteria, and an assessment of the accuracy and precision of analytical data from the range of quality control indicators generated from the sampling and analytical programmes.

The majority of the quality control results indicated that the precision and accuracy of the data was within acceptable limits; minor non-conformances identified are discussed in the following paragraph

Matrix spike (MS) and laboratory control sample (LCS) frequencies were not undertaken on a majority of the primary batches, which is considered a non-conformance given these test the accuracy and performance of the analytical methods. However, where MS and LCS were undertaken on primary and secondary batches, the majority of results were within acceptable ranges, noting that the primary batches consistently reported bias high. Furthermore, the RPDs generally showed the inter-laboratory duplicates (secondary lab) reported results at lower concentrations that the primary laboratory, where the secondary laboratory batches had acceptable QAQC. This is not anticipated to impact the conclusions drawn as the duplicate and triplicate results were relatively closely correlated with few exceedances of adopted criteria.

On the basis of this, some of the primary results may have bias (high), however this was considered acceptable for the purpose of the site investigations, given the non-conformances result in a more conservative assessment as part of the DSI and HHERA by being based on the higher of the concentrations.

In summary, the results are considered representative of chemical concentrations in the environmental media at the time of sampling, and are suitable to be used for their intended purpose in providing an understanding of the contamination status of the environmental media assessed for the HHERA. A detailed discussion of non-conformances is presented in the DSI, Appendix J (Senversa, 2021b).

The limitations and areas of uncertainty identified in the PSI/DSI include the following:

- The assessment of groundwater conditions was limited to sampling of bores already present. There is little information on groundwater conditions beneath on site PFAS source areas, likely areas of discharge and concentration trends.
- The nature and extent of PFAS impacts in surface water and sediment, and assessment of concentration trends may require further investigation within the Mission Creek Catchment, potentially including at the discharge point of Mission Creek and the WWTP.
- Produce (fruit, vegetables and chicken eggs) were sampled at one property where the highest PFAS concentrations in water known to be used for watering chickens and irrigating produce, and therefore this testing is assessed to be adequate for assessment of other properties.
- For pathways of uptake into cattle, no cattle serum data was collected as part of this investigation, and therefore, the cattle assessment will be initially undertaken on the basis of PFAS concentrations in stock water. The requirement for testing of cattle will be assessed based on the results of this assessment.

3.4 COPC selection

The contaminants of potential concern (COPC) considered in this HHERA are Per- and poly-fluoroalkyl substances (PFAS), associated with the historical use of AFFF at the airport.

PFAS contains a large number of different compounds. This HHERA has assessed only perflouorooctane sulfonate (PFOS) and perflourohexane sulfonate (PFHxS) as COPC, as relevant Australian guidance and industry experience at other sites predominantly indicates that these PFAS:

- Have as high or higher toxicity than most other PFAS for which toxicological studies have been conducted (e.g. see Zeilmaker, 2018);
- Have screening and toxicity reference values published by Australian agencies for use in both screening level and detailed quantitative HHERAs; and
- Comprise the majority of total analysed PFAS compounds at Australian sites where PFAS-containing fire-fighting foams have been used.

Both PFOS and PFHxS are assessed for the human health risk assessment; for the ecological assessment, the focus is on PFOS only, in accordance with the PFAS National Environmental Management Plan (NEMP), which presents ecological screening levels in soil for PFOS but not PFHxS.

It is noted that toxicity reference values (TRVs) and screening levels are also available for Perfluorooctanoic acid (PFOA), however PFOA has not been demonstrated to be a risk driver at Australian sites, due to its lower toxicity than PFOS and PFHxS and its occurrence at lower concentrations in environmental media.

The conclusion that PFOA is unlikely to be a risk driver is supported by the results of the DSI, which found PFOS and PFHxS to be present at the highest concentrations. Concentrations of PFOA were lower: only a small number of localised PFOA exceedances were identified and in these samples concentrations of PFOS and PFHxS were always higher (normally orders of magnitude higher). The key risk drivers for the human health assessment are therefore PFOS and PFHxS, and the key risk driver for the ecological assessment is PFOS.

To further assess the validity of the third statement above (i.e. whether PFOS and PFHxS comprise the majority of the identified impacts) the ratios of PFOS+PFHxS to total PFAS concentrations in samples collected in the DSI have been evaluated, as shown in **Appendix A**.

This analysis indicates the following:

- On-airport soils: the arithmetic average and median ratios of PFOS+PFHxS:Total PFAS were 81% and 86%, respectively, and the estimated ratio based on linear regression was 94% (R^2 = 0.9917).
- Surface water: the arithmetic average and median ratios of PFOS+PFHxS:Total PFAS were 87% and 100%, respectively, and the estimated ratio based on linear regression was 81% (R^2 = 0.9976).
- Other water (e.g. bores, tanks, taps): the arithmetic average and median ratios of PFOS+PFHxS:Total PFAS were 88% and 84%, respectively, and the estimated ratio based on linear regression was 84% (R^2 = 0.999).

This indicates that PFOS+PFHxS generally comprise at least 80-90% of total PFAS in both on-airport soil and waters samples across the island. The remaining unevaluated PFAS (around 10-20%) is considered to be relatively small in comparison to the overall uncertainties and safety factors incorporated in the HHERA process, and in comparison to expected levels of sampling and analytical variability (generally reported by laboratories to be 30-50% for PFAS in environmental media).

In addition, it is likely that some if not all of the other PFAS have lower toxicity than PFOS and PFHxS, and therefore that detailed assessment of PFOS and PFHxS will be protective. By way of example, the composition of PFAS in sample PWS_WWII_DAM (i.e. in water from the WWII dam in Mission Creek near the airport) has been reviewed. This sample was selected for this review, as off-site surface waters represent a key exposure medium for the pathways assessed in the HHERA, and this is the water sample in which the highest concentrations of PFAS (both PFOS+PFHxS, and also PFAS other than PFOS and PFHxS) have been measured.

In this sample, PFOS+PFHxS makes up 84% of the measured PFAS. The composition of the remaining PFAS (i.e. making up only 16% of the identified PFAS) is summarised in **Figure 3-1** below.

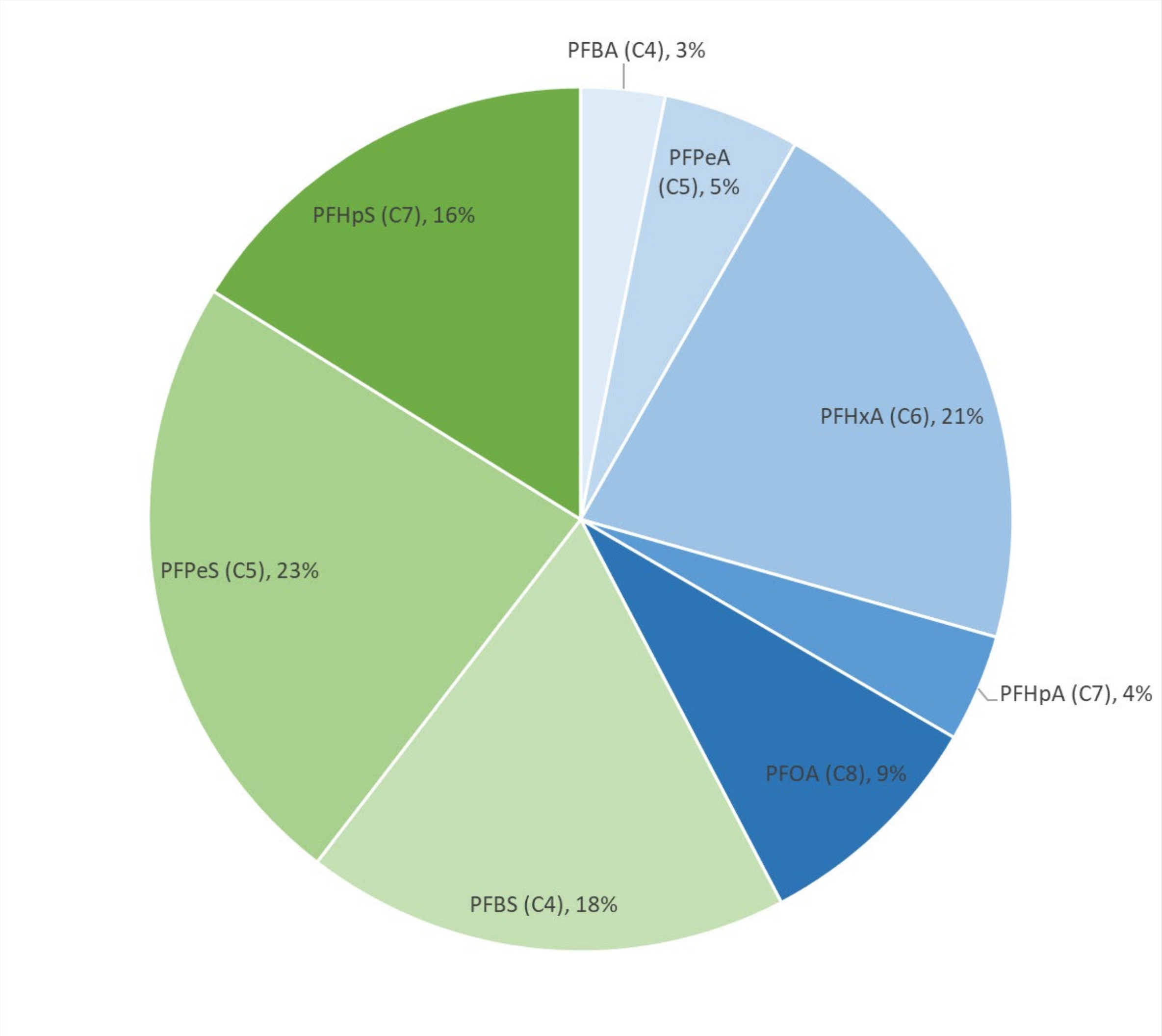


Figure 3-1: Composition of PFAS other than PFOS and PFHxS in PWS_WWII_DAM

The detected PFAS other than PFOS and PFHxS are composed entirely of sulfonic acids (PFSAs) (depicted above in green), and carboxylic acids (PFCAs) (depicted above in blue) and

- The PFSAs (green) are a group of PFAS than includes PFOS and PFHxS
  - The remaining PFSAs are composed of perfluorobutane sulfonic acid (PFBS) perfluoropentane sulfonic acid (PFPeS) and Perfluoroheptane sulfonic acid (PFHpS)
  - These PFSAs might be expected to have lower toxicity than PFOS, as a result of their shorter chain length[1].
- The PFCAs (blue) are a group of PFAS than includes PFOA
  - PFCAs are of generally lower toxicity than PFOS and PFHxS, as evidenced by the much lower toxicity of PFOA when compared with PFOS and PFHxS.
  - The PFCAs are largely composed of perfluorohexanoic acid (PFHxA) and Perfluorooctanoic acid PFOA. PFHxA might be expected to have lower toxicity than PFOA, as a result of its shorter chain length

[1] Short-chain PFAS generally exhibit lower toxicity than longer-chain PFAS. This is likely to relate at least in part to the way PFAS behaves in the human body. Shorter chain PFAS are more readily and quickly eliminated from the body. Because of this, for a given concentration in the environment (and a given intake), the PFAS concentration which reaches internal cells will be lower for shorter chain PFAS when compared with longer chain PFAS, resulting in lower toxicity (Gomis et al., 2018).

On the basis of this review, it is concluded that the PFAS other than PFOS and PFHxS are likely to be of generally lower toxicity than PFOS and PFHxS. Taken together with the fact that PFOS and PFHxS make up the majority (80-90%) of the identified PFAS, this supports an approach focussing on the evaluation of PFOS and PFHxS alone.

3.5 Data utilised in the risk assessment

All data collected in the PSI and DSI has been considered in the HHERA. In addition, the data collected in previous investigations undertaken by CSIRO has also been referenced as appropriate, noting that for sampling locations where more current data collected by Senversa is available, this is considered the most relevant data for inclusion in the assessment.

Multiple pathways assessed, these are assessed individually in Sections 5.0 to 10.0 (human health) and Sections 12.0 and 13.0 (ecological). The data selected as relevant for each pathway has been discussed as part of the assessment for that pathway.

4.0 Human health toxicity assessment

4.1 General properties of PFAS

PFAS are a large group of fluorinated compounds which were first manufactured in the 1940's and have been widely used for a number of industrial applications and consumer products since. PFAS form strong surfactants which are utilised in applications requiring heat resistance, dispersion of liquids, fire suppressant and surface protection (NICNAS, 2016). The pervasive use of PFAS in products and industrial processes over decades and its resistance to break down, has resulted in PFAS being detected throughout the environment from other non-AFFF sources.

PFAS are characterised by fluorinated carbon chains where hydrogen atoms have been replaced with fluorine atoms; the resulting carbon-fluorine bond is the strongest in organic chemistry and PFAS are subsequently highly resistant to degradation (Grijalva & Manuel, 2009). The fluorinated carbon forms a hydrophobic linear chain (typically C_4 to C_{16}) and an attached functional group creating a hydrophilic component. This structure results in variable surface active (polar and non-polar) properties.

PFOS ($C_8F_{17}SO_3$) is the most common PFAS found in the environment due to its widespread historic use and its physico-chemical characteristics. PFOS is also the ultimate degradation or metabolic perfluorinated compound for a number of longer chain PFAS. PFOS, CAS number 1763-23-1, is a sulfonic acid and includes the anionic, acid and salt forms. PFOS is listed as a persistent organic pollutant (POP) under the Stockholm Convention. PFHxS ($C_6HF_{13}O_3S$), is another PFAS compound commonly identified in the environment. PFHxS, CAS number 355-46-4, is a completely fluorinated organic acid comprised with of 6 carbon atoms and a sulfonate group. PFHxS is considered to be structurally similar to PFOS.

The per-fluorinated sub-group of PFAS (including PFOS and PFHxS) are highly resistant to metabolic break down in the environment as environmental degradation processes generally do not possess the energy needed to break the strong fluorine-carbon bonds within the perfluoroalkyl chain (ATSDR, 2015; OECD, 2002). As a result, these compounds tend to bioaccumulate and biomagnify up the food chain, with highest concentrations of perfluoroalkyl compounds measured in apex predators (ATSDR, 2015). PFAS bioaccumulate by attaching to proteins in the blood rather than in accumulating in lipids (USEPA 2014a). Estimated half lives in humans range from 2.3 – 8.67 years.

4.1.1 Exposure

The main routes of exposure to PFOS and PFHxS are likely to be ingestion of contaminated water or food. PFAS may occur in food as a result of contamination of plants and animals, and/or via transfer from food-packaging materials.

Both compounds are essentially non-volatile and the general public would not be expected to be exposed via inhalation (NSW EPA, 2017).

While data are not available for PFOS and PFHxS, available literature studies regarding dermal absorption of PFOA indicate that, at normal environmental and/or skin pH levels, rates of absorption through the skin are negligible. For example, Fasano et al. (2005) estimated that only 0.048% of PFOA in aqueous solution penetrated human skin after a 48-hour exposure period, and estimated a dermal permeability coefficient through human skin on the order of $1x10^{-6}$ cm/hr. These results are consistent with a subsequent study by Franko et al. (2012), who showed that at neutral or normal stratum corneum pH (approximately 5.5), PFOA is largely ionised and therefore very little skin penetration occurs (estimated dermal permeability coefficients were approximately $4.4x10^{-5}$ cm/hr). Based on its similar chemical structure, PFOS is also expected to be largely ionised at normal skin pH and therefore to be negligibly absorbed through the skin.

4.2 Non-carcinogenic Health Effects

Associations between PFOS exposure and several health effects have been reported in a number of epidemiological studies, although a number of findings are inconsistent between studies and the biological significance of some of the observed effects is questionable (FSANZ 2017).

Additional difficulties arise when seeking to extrapolate from animal to human studies, as humans and animals have been found to react differently to PFOS, with profound differences in the toxicokinetics observed (ATSDR 2015). In addition, the mechanism of PFOS uptake in animals is not fully understood (ATSDR 2015).

The available epidemiological studies suggest that increases in blood cholesterol levels are associated with higher PFOS blood levels in workers exposed to PFOS. However, it is noted that the occupational exposure concentrations are considerably higher than those associated with environmental exposures. There are data to suggest an association between serum PFOS levels and increased uric acid levels, which may be associated with an increased risk for high blood pressure. There is also some evidence that PFOS exposure may cause liver damage (ATSDR 2015). There are considerable uncertainties in the human data for PFAS, a discussion on the animal and epidemiology data for PFOS is presented below.

4.2.1 PFOS

The US EPA 2016 evaluated epidemiology studies (in humans) and identified associations with PFAS in environmental media and health effects. The two health effects that appear to be reasonably consistent and repeatable are those with increased serum cholesterol and decreased body weights in offspring. FSANZ (2017) reviewed the available epidemiological data relating to PFAS exposure and serum cholesterol as well as changes to birth weight. Overall the cross-sectional studies show a fairly consistent finding of a positive association between total and LDL cholesterol at low serum concentrations of PFOS, with the association plateauing at higher PFOS levels. However, a number limitations were observed including that some studies note a correlation between concentrations of PFOS but do not adjust the results for each other. Similarly, populations with high exposure to PFAS may also be exposed to other contaminants but these have not been considered in the studies, and most studies do not adjust for diet. FSANZ (2017) also concluded that it is currently not possible to determine whether the association with decreased body weight and PFAS exposure reflects a causal relationship or is the result of a third factor that alters both PFAS concentration and birthweight.

There have been a range of animal studies to assess the acute and short term toxicity in mice, rats and monkeys, subchronic studies in rats and monkeys, as well as chronic studies in rats, and developmental and reproduction studies in mice, rats and rabbits. In repeat dose studies, the primary target organ was the liver, however developmental toxicity has also been observed.

In general, observations from toxicological studies undertaken in animals with PFOS include irritation of eyes, skin and nose; loss of appetite, reductions in body-weight and weight gain, changes in the liver, mild-to-moderate peroxisome proliferation in rats, increased incidence of hepatocellular adenomas in rats (non-genotoxic), and hypo-cholesterolemia (low cholesterol) (ATSDR 2015). FSANZ 2017 conclude that PFOS has moderate acute toxicity following oral ingestion.

No evidence has been found that PFOS undergoes any metabolism in studies conducted in rodents or non-human primates. In both humans and laboratory animals, PFAS cross the placenta and are also found in milk (USEPA 2016). PFOS is principally excreted by the renal route, menstruation and lactation are also considered to be an excretory pathway for PFOS (FSANZ 2017). The elimination half-life of PFOS in humans is 5.4 years (range 4.1-8.67 years), whereas the half-lives in monkeys, rats and mice are much shorter, 121, 48 and 37 days respectively (US EPA 2016).

4.2.2 PFHxS

There are a number of epidemiological studies of human populations that have explored the association between PFHxS exposure and various health endpoints but evidence of significant risk is poor and at times contradictory (FSANZ 2017).

ATSDR (2015) considered a number of epidemiological studies that have reported an association between PFHxS exposure and health effects in human populations. However overall the evidence was contradictory between serum PFHxS levels and physician-diagnosed asthma in children, total cholesterol, LDL cholesterol and non-HDL cholesterol, sperm quality and effects on birth weight.

FSANZ 2017 concluded there are currently substantial deficiencies in the toxicological and epidemiological database for PFHxS, and other PFAS (with the exception of PFOS and PFOA).

FSANZ 2017 concluded that the enHealth approach of using the TDI for PFOS is likely to be conservative and protective of public health as an interim measure for the assessment of PFHxS. The approach recognises that the structure of PFHxS and PFOS are similar, and that there is some evidence of similar potency of PFHxS and PFOS.

Effectively, this means that as a conservative approach, PFHxS and PFOS concentrations should be summed for the purposes of a dietary exposure assessment and risk characterisation.

4.3 Carcinogenicity and Genotoxicity

PFOS and PFHxS have not been evaluated or classified by the International Agency for Research on Cancer (IARC).

FSANZ 2017 concluded that epidemiological studies have not provided convincing evidence of a correlation between PFOS and any cancer type in humans.

Increased liver tumour incidence has been reported in rats following exposure to PFOS, however this appears to be due to a non-genotoxic mode of action. Further, increased tumour incidence has been observed at doses above those associated with non-neoplastic toxic effects. EFSA (2008) and the US EPA (2016) concluded that PFOS is not genotoxic based on negative findings in in vitro and in vivo tests. Assessment of PFOS using threshold toxicity criteria is therefore considered appropriate.

4.4 Toxicity Reference Values

In April 2017, FSANZ published toxicity reference values (TRVs) or tolerable daily intakes (TDIs) for the COPC for this HHERA (PFOS and PFHxS. These FSANZ TRVs are referenced in both the PFAS NEMP (HEPA, 2018) and the PFAS NEMP 2.0 (HEPA, 2020) and are accepted by regulatory authorities for use in Australia and hence they have been adopted in this HHERA:

For PFOS, FSANZ (2017) recommended a TDI of 20 ng/kg bw/day on the basis of decreased parental and offspring body weight gains in a multigeneration reproductive toxicity study in rats. The TDI was derived by applying pharmacokinetic modelling to the serum PFOS concentrations measured in experimental animals at the NOAELs in these and other critical studies, to calculate human equivalent doses. An uncertainty factor (UF) of 30 was applied based on a factor of 3 to account for interspecies differences in toxicodynamics and a factor of 10 for intraspecies differences in the human population.

For PFHxS, FSANZ (2017) concluded as follows:

> *"There was insufficient toxicological and epidemiological information to justify establishing a TDI for PFHxS. In the absence of a TDI, it is reasonable to conclude that the enHealth 2016 approach of using the TDI for PFOS is likely to be conservative and protective of public health as an interim measure. Effectively, this means that PFHxS and PFOS should be summed for the purposes of a dietary exposure assessment and risk characterisation."*

In this HHERA, the TDI for PFOS is adopted for both PFOS and PFHxS.

5.0 Risk assessment for cattle and other livestock

5.1 Issues Identification

PFAS is bioaccumulative. This means that there is the potential for PFAS to accumulate in the bodies of humans and animals exposed to PFAS over time. For livestock such as cattle, exposure to PFAS can potentially occur via drinking water (when PFAS is present in the water), and also through feed (i.e. through the consumption of pasture such as grass grown in PFAS impacted soils). This exposure can result in the build up of PFAS within the different tissues of the livestock (e.g. in the muscles, bones, fat and other organs). The potential for PFAS build up in the tissues of livestock is greatest when there is continuous exposure over a long period, and will be reduced if exposure is intermittent.

People consuming livestock products (e.g. meat, offal) into which PFAS has been taken up may themselves be exposed to PFAS. It is understood that livestock products consumed from livestock raised on island include beef cattle products (potentially including beef, tallow, offal and bones), dairy cattle products (milk, cheese) and pig products (pork). Different livestock are present in different parts of the island, and not all livestock are potentially exposed to PFAS.

The DSI identified PFAS in water used for stock watering, and within grass potentially eaten by livestock. However, no screening levels were identified in the DSI to assess pathways of human consumption of livestock. This HHERA will therefore assess the potential risks associated with people who consume livestock products from livestock raised on-island and exposed to PFAS (within stock water and feed).

It is emphasised that there are no regulatory restrictions with respect to PFAS in livestock products (including cattle products) and that, currently, there are no regulated maximum limits for PFAS in any foods in Australia or overseas[2] but research is ongoing. FSANZ has set precautionary trigger points for meat and offal guiding the recommendation for further study, and these trigger points have been considered in this risk assessment.

5.2 Risk assessment approach

The overall approach followed in the livestock risk assessment is as follows:

- Conservative screening levels for water used for stock watering, and grass eaten by livestock have been derived.
- The concentrations of PFAS have been compared to these screening levels to assess potential risks
- Where concentrations are below the screening levels, risks are assessed to be low and acceptable, and further assessment is not required.
- Where exceedances are identified, further assessment has been undertaken to assess potential risks in more detail.

[2] SAFEMEAT, 2019. Issues brief: LPA and per- and polyfluoroalkyl substances (PFAS). Available from the Australian Government PFAS information portal (https://www.pfas.gov.au/audience/business)

5.3 Areas where assessment is required

The data regarding PFAS impacts in water potentially used for stock water, and in grass potentially eaten by livestock is summarised below:

- **Stock watering in Mission Creek:** PFAS has been identified in water known to be used as drinking water by beef cattle within the Mission Creek catchment. This includes a small number of properties where water from Mission Creek and/or groundwater from the Mission Creek catchment is currently pumped up to fill stock watering troughs, together with paddocks where cattle may have direct access to drink from Mission Creek when there is water present within the creek.
- **Stock watering in other areas:** Much lower concentrations of PFAS are present in creeks and other potential sources of stock water in other areas of the island. While detailed water use information is generally not available for properties outside of the Mission Creek catchment, some of these creeks and other water sources may be used for livestock watering. Although only beef cattle have been identified in the Mission Creek catchment, there are a range of livestock raised across the broader island, including beef cattle, dairy cattle, sheep and pigs. **Figure 1** (presented at the end of the report) presents a broad overview of the livestock which potentially graze in different areas of the island.
- **Grass in Mission creek:** PFAS was identified within grass growing in the creek bed of Mission Creek bed, which may be potentially consumed by beef cattle. This pathway has been included in order to assess whether management of cattle access to this grass may be warranted; however, inclusion of this pathway in the assessment is a conservative approach, for the reasons given below:
  - Soil has been sampled away from the creek within the Mission Creek catchment (including within proximity of the creek bed) and only very low concentrations of PFAS (<0.005 mg/kg PFOS) have been identified; grass concentrations other than in the creek bed are therefore assessed to be negligible. This is consistent with the absence of identified off-airport sources, and the understanding that water is generally not used for irrigation of pasture (therefore irrigation with PFAS-impacted water does not present a plausible pathway for PFAS to accumulate in soil and grass within paddocks.
  - Only very localised grass impacts have been identified (i.e. within the creek bed of Mission Creek); in paddocks which Mission Creek crosses, the creek bed only makes up a very small proportion of the area of the paddock (see **Figure 5-1** below); as such the majority of the grass in these paddocks is assessed to be unimpacted, and grass impacted with PFAS is therefore very unlikely to form a significant part of the diet of livestock.
  - Furthermore, while cattle in paddocks with access to Mission Creek may drink water from Mission Creek in addition to having access to grass, the potential for simultaneous exposure via grass and creek water are unlikely to occur simultaneously. At times of creek flow, cattle will have access to Mission Creek water as drinking water, but grass would not be consumed from the areas where water is present at these times, further reducing the area across which grass could be consumed. When the creek is dry, this would maximise the area across which grass could be consumed, but there would not be access to creek water for drinking. As such, detailed assessment of cumulative exposure via grass and stock water is assessed to be unwarranted.

Figure 5-1: Aerial photography showing the course of Mission Creek across several example paddocks, and depicting the very small proportion of the paddocks comprising the creek bed where PFAS may be present in grass

- **Grass from the airport:** Much lower concentrations of PFAS were identified in grass from the airport (which is potentially mown and used for beef cattle fodder). Of 20 samples analysed across the airport, PFAS was identified in only two samples, with the only detection PFOS at a concentration of 0.001 mg/kg (i.e. at the detection limit) in two samples. Grass sampling at the airport was focussed in source areas with additional samples across the airport analysed to provide broad coverage. As PFAS was generally not detected risks are expected to be low. However, further assessment has been completed as a confirmatory measure.
- **Grass in other areas:** Away from Mission Creek and the airport, the potential for livestock to be exposed via their fodder is likely to be negligible. Grass concentrations in other areas of the island (away from Mission Creek and the airport) are assessed as likely to be low, given the absence of identified PFAS sources in grazing areas. Where PFAS is not present in the soil, it will not be present in the grass grown in these soils.

The key potential exposures are associated with beef cattle raised in the Mission Creek catchment. This assessment will consider the measured concentrations in water used for stock watering and in grass potentially eaten by cattle. In addition, the assessment will consider:

- The PFAS concentrations in other creeks on island to assess the risks associated with potential use of this water for stock watering whether risks to livestock.
- The PFAS concentrations in grass from the airport, to assess the risks associated with using this grass for beef cattle fodder.

5.4 Livestock on Norfolk Island

5.4.1 Overview

It is understood from discussions with people on-island that livestock products consumed from livestock raised on island are primarily beef cattle products (potentially including beef, tallow, offal and bones). Other livestock are raised on island, including sheep, dairy cows and pigs, but the consumption of these is assessed to be less significant. This is due to the smaller volumes of these foods being eaten, and the location of the grazing of these animals away from Mission Creek, where the highest concentrations of PFAS have been identified.

Key information regarding the rearing of different livestock, and the consumption of associated livestock products is summarised below.

5.4.2 Beef cattle

Beef cattle are grazed across the island including within the Mission Creek catchment. Products from beef cattle are the most significant contributors to the consumption of on-island produce. Key information regarding the rearing of cattle and the consumption of beef cattle products is summarised below:

- There are approximately 300-400 cattle on island at any time, with 15-20 cattle sent for slaughter each month.
- Cattle graze across much of the island, other than in restricted areas (as shown on **Figure 1** presented at the end of the report). Some cattle are kept on private properties and others roam freely on roads verges and common areas. Many cattle are mustered (i.e. moved between different grazing areas) based on pasture availability, with such mustering occurring approximately every six months, and most cattle do not stay in one place for extended periods.
- The Mission Creek catchment is a key area within which cattle exposure to PFAS may occur, as the highest concentrations of PFAS in water are identified in this catchment. Within the Mission Creek catchment, exposure is conceptualised to be limited to those cattle utilising fenced paddocks with access to water from Mission Creek (whether through pumping, or where the creek crosses the paddock):
  - There are several private properties where cattle graze and are watered with water from Mission Creek. Some of these cattle will be brought onto these properties to graze for only limited periods, but other cattle may be mainly rotated within paddocks within the Mission Creek catchment, where they are watered primarily with water from Mission Creek.
  - Exposure to water from Mission Creek is conceptualised to be largely limited to the cattle which use these paddocks. Road cattle are generally unlikely to access Mission Creek for drinking (as evidenced by the absence of easily accessible creek sampling points on unfenced public land, including road crossings). An exception to this is Mission Pool, which is located within Stock Reserve (which is a public reserve used for cattle grazing / stock watering). No water has been identified within Mission Pool (within Stock Reserve) during the investigations completed by Senversa, however, cattle using this reserve at times when water is present would have potential access to water from Mission Creek for drinking.
- A key area outside the Mission Creek catchment where cattle roam is around Kingston Common (shown on **Figure 1**). Cattle generally do not stay in one location for extended periods; they will move based on the availability of pasture. It is noted that in this area, the creek (Watermill Creek) is now fenced to limit cattle access, as cattle were causing damage to the creek. Cattle in this area are currently watered from stock troughs, with the water understood to be sourced from Hessies Reservoir, which has been sampled by Senversa (ID: PWS_HESSIES_RESV) and found to contain only low concentrations of PFAS (0.01 µg/L PFOS; <0.02 µg/L PFHxS)
- Some cattle are raised for home consumption, while others will be sold through local butchers or will be used in restaurants (primarily tourist consumption). Tourist exposures are likely to be less significant, due to the absence of chronic exposure.

- Islanders do not eat only beef, but many other parts of the animal, including offal, fat (as tallow) and bones (for stock).
- Few local people would eat local beef every day, due to limited availability. Approximately 20 – 30 % of the beef sold by butchers on island is local beef, and much of this goes to the tourist / restaurant trade. The remainder of beef consumed on island is imported, and there are sometimes periods where no local beef is available for sale.

5.4.3 Sheep

Some sheep are kept, with sheep understood to graze within the Watermill Creek catchment. Lamb is generally raised for home consumption, and the consumption rates of lamb are likely to be less than beef consumption

5.4.4 Dairy cows

Dairy cows are kept, but in limited numbers. The known area of dairy cattle grazing is within the Stockyard Creek catchment, away from potential PFAS sources. The on-island dairy is understood to be closed, but milk from dairy cows may be used for the production of small volumes of cheese, generally consumed as a tourist product, rather than eaten in significant volumes by locals.

5.4.5 Pigs

A small number of pigs are kept, with reported locations including Watermill Creek catchment and Stockyard Creek catchment, near Ball Bay. There are no major growers, with approximately 5-10 pigs kept as a maximum and most private properties keeping only 1 or 2 animals.

It is understood that pork is generally raised for home consumption with some pork sent to restaurants and only limited sent to local butchers (e.g. 4 animals per year). It is also understood that some owners may destock their pigs during periods of drought or poor food availability, and pigs may therefore not be continuously kept.

5.5 Summary of assessed consumption pathways

Based on the location of PFAS impacts relevant to livestock exposure pathways (**Section 5.3**) and information regarding the keeping of different livestock types in different parts of the island, the pathways requiring further assessment have been determined.

Table 5-1 below summarises the livestock consumption exposure pathways associated with the Mission Creek catchment, and how these are to be assessed in the HHERA. These represent the key livestock exposure pathways considered in the assessment:

Table 5-1: Livestock consumption pathways: Mission Creek

Livestock	Produce type	Assessed quantitatively in the HHERA?
Beef cattle	Meat and offal (liver, kidney)	Yes – based on measured concentrations in water known to be used for stock watering, and grass which cattle may access for feed. The majority of cattle on island will not be exposed to water or grass within the Mission Creek catchment. The assessment is undertaken for those cattle utilising fenced paddocks with access to water from Mission Creek (whether through pumping, or where the creek crosses the paddock). Some of these cattle may be exposed to PFAS in stock water for a limited period, while others may drink primarily this water. The assessment assumes cattle exposed via stock water may be continuously exposed, and the results of this assessment are conservatively applied for all cattle which utilise these paddocks. This approach will be conservative for the cattle which use these paddocks, but which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water).
	Other (tallow, bones)	Comparative assessment only. As discussed in **Appendix B** PFAS compounds have a relatively low potential to accumulate in bone and bone marrow relative to other tissues. On this basis, the assessment completed for meat an offal is considered conservative for other cattle products which may be consumed.

Across the broader island, PFAS concentrations are lower, and therefore potential exposures associated with livestock exposure pathways will be lower. Furthermore, there is more limited information regarding potential livestock exposures, as land and water use surveys have been focussed on the Mission Creek catchment where the PFAS concentrations are higher. Full details around the keeping of livestock on individual properties, together with information regarding potential exposures (e.g. the range of water sources used for livestock consumption) are unknown.

On this basis, the overall approach for assessing potential livestock consumption risks in areas of the island away from Mission Creek is comparison of measured concentrations in creeks to stock watering screening levels. This is a conservative approach because it is likely that not all of the creek waters included in this assessment are utilised for stock watering, and even if the water is used for stock watering, the measured concentrations may over-estimate the overall concentrations to which livestock are exposed (e.g. if water is supplemented with other sources). If creek concentrations are below screening levels, this will allow potential risks to be excluded. Conversely, if exceedances are identified, this will indicate that further assessment is required, including liaison with landholders to identify whether and to what extent these waters are utilised for stock watering.

Table 5-2 below summarises the livestock consumption exposure pathways associated with the Mission Creek catchment, and how these are to be assessed in the HHERA.

Table 5-2: Livestock consumption pathways: broader island

Livestock	Produce type	Assessed quantitatively in the HHERA?
Beef cattle	Meat and offal (liver, kidney)	Yes – based on conservative comparison of creek concentrations to stock watering screening levels **Some cattle may be exposed to PFAS in stock water for a limited period, while others may drink primarily this water. The assessment assumes cattle exposed via stock water may be continuously exposed, and the results of this assessment are conservatively applied for all cattle. This approach will be conservative for livestock which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water).**
	Other (tallow, bones)	Comparative assessment only. As discussed in **Appendix B**, PFAS compounds have a relatively low potential to accumulate in bone and bone marrow relative to other tissues. On this basis, the assessment completed for meat an offal is considered conservative for other cattle products which may be consumed.
Sheep	Meat and offal (liver, kidney)	Yes – based on conservative comparison of creek concentrations to stock watering screening levels
Dairy cows	Milk, milk products	Yes – based on conservative comparison of creek concentrations to stock watering screening levels
Pigs	Meat, offal	No There is limited literature data on which to estimate screening levels for pigs. On this basis, when coupled with the limited information regarding where pigs might be kept and stock watering sources for these animals, further assessment has not been undertaken at this stage. As noted in **Section 5.4.5**, the keeping of pigs is limited on island and consumption rates are likely to be generally lower than for other livestock types. On this basis, where risks from other livestock produce are assessed to be low, it is unlikely that elevated risks would be associated with the consumption of pork and other pig products. Notwithstanding this, risks cannot be fully excluded without additional information and/or assessment. This is noted as a data gap; the requirement for further assessment/management of this pathway should be further assessed as part of the PFAS Management Plan.

5.6 Screening level derivation

Screening levels have been derived for a range of livestock consumption pathways.

These screening levels represent the concentrations which can be present in water used for stock watering or grass used for livestock feed without unacceptable risks being posed to consumers of this produce.

The screening levels are conservatively defined:

- They assume that 100% of the diet of people consuming these products comes from impacted sources. As discussed in **Section 5.4**, this is likely to be a highly conservative assumption.
- The screening levels for stock water assume continuous exposure of livestock to these concentrations within PFAS-impacted water. Where livestock source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water), their exposure to PFAS will be lower, and these screening levels are conservative.
  - The ephemeral nature of the creeks on-island means in most locations it is unlikely that livestock will be exposed continuously to the measured concentrations of PFAS within creeks. This is an area of conservatism in the stock watering screening levels.
- The screening levels for grass have been derived for comparison with PFAS concentrations in grass from the creek bed of Mission Creek and the airport (see discussion in **Section 5.3**). The screening levels assume that PFAS-impacted grass makes up 5% of the long-term diet of cattle which consume this grass. This is assessed to be a conservative assumption:
  - **Mission Creek:** Exposure is restricted to those cattle which have access paddocks which Mission Creek crosses. Most cattle on island will have no access to grass in the Mission Creek bed. Only very localised grass impacts have been identified within the creek bed of Mission Creek (see **Figure 5-1** above); the proportion of these paddocks made up of the creek bed (where impacted grass is presented) is <5%, and therefore this grass is extremely unlikely to form a significant part of the diet of cattle using these paddocks, as cattle will source grass from across the paddock, and at times of creek flow would not source grass from within the impacted area. As such, this is considered to be a conservative assumption for cattle permanently in paddocks with access to Mission Creek, and a highly conservative assumption for cattle which may visit these paddocks intermittently.
  - **Airport:** For the collection of cut grass from the airport as supplementary cattle feed, this is also assessed as unlikely to make up a significant part of the diet for individual cattle over the longer term. The assumption of 5% of the long-term diet is therefore considered conservative.

Given the high degree of conservatism in the screening levels as highlighted above, they are considered appropriate and protective, and provided individual concentrations remain below the concentrations, risks are assessed to be negligible, and further investigation is not warranted. Furthermore, the identification of exceedances does not necessarily indicate that unacceptable risks are posed, merely that further investigation and/or assessment is warranted.

Reference should be made to **Appendix C** for full details of the derivation. The screening levels are presented in **Table 5-3:**

Table 5-3: Livestock consumption screening levels – stock water

Livestock	Produce type	Stock water screening level (µg/L)	
		PFOS	PFHxS
Beef cattle	Meat, offal	0.33	1.2
Sheep	Meat, offal	1.6	1.1
Dairy cows	Milk, milk products	1.0	6.5

Table 5-4: Livestock consumption screening levels – grass

Livestock	Produce type	Grass screening level (ww grass) (mg/kg)	
		PFOS	PFHxS
Beef cattle	Meat, offal	0.03	0.1

5.7 Screening assessment: stock watering

5.7.1 Mission Creek

The majority of cattle on island will not be exposed to water within the Mission Creek catchment. The assessment is undertaken for those cattle utilising fenced paddocks with access to water from Mission Creek (whether through pumping, or where the creek crosses the paddock). On-island investigations have indicated there are a number of properties within the Mission Creek catchment where water containing PFAS is used to water beef cattle. This includes a small number of properties where there is no direct access to Mission Creek, but where water from Mission Creek and/or groundwater from the Mission Creek catchment is currently pumped up to fill stock watering troughs, together with paddocks where cattle may have direct access to drink from Mission Creek when there is water present within the creek.

Some cattle within these paddocks may be exposed to PFAS in stock water for a limited period, while others may drink primarily this water. The screening levels assume cattle exposed via stock water may be continuously exposed, and the results of this assessment are conservatively applied for all cattle which use these paddocks. This approach will be conservative for livestock which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water).

PFAS concentrations in water used or potentially used for stock watering in the Mission Creek catchment are compared to the screening levels developed for beef cattle in **Table 5-5** below.

Table 5-5: Stock water screening assessment for Mission Creek

COPC	Stock water (µg/L)					
	Screening level (beef cattle)	Property A (water is pumped to this property)		Property B (water is pumped to this property)		Property C (cattle access Mission Creek directly)
		2020	2021	2020	2021	2021
PFOS	0.33	**1.93**	**0.89**	**0.46**	0.15	**3.53**
PFHxS	1.2	1.2	1.04	0.63	0.3	**3.48**

Concentrations of PFOS exceeding the screening level were identified at 3 properties using water from Mission Creek to water beef cattle:

- **Property A:** the concentration of PFOS exceeded the screening level in both 2020 and 2021, though concentrations were lower in 2021. No PFHxS exceedances were identified. Given the conservatism in the screening levels, it is recommended that further assessment be undertaken to better understand the level of risk to consumers of produce from this property.
- **Property B:** the concentration of PFOS in 2020 marginally exceeded the screening level, but the concentration was below the screening level in 2021. No PFHxS exceedances were identified. Based on the most recently measured concentrations at this property, the risks are assessed to be **low and acceptable**. However, it is recommended that water sampling be completed to establish the trend in water concentrations
- **Property C:** the concentration of PFOS and PFHxS exceeded the screening level. Given the conservatism in the screening levels, it is recommended that further assessment be undertaken to better understand the level of risk to consumers of produce from this property.

Further assessment of the risks on all three properties has been conducted in **Section 5.10**.

5.7.2 Potential livestock water sources outside Mission Creek

5.7.2.1 Creeks where PFAS has not been identified

PFOS was not detected at concentrations above the limit of reporting (LOR) in the following creeks:

- Broken Bridge Creek up-gradient of the confluence with Cascade Creek.
- Town Creek, up-gradient of the confluence with Watermill Creek.
- An unnamed creek in Broken Bridge catchment, north of Mission Creek (where sample ID007_SPRING was collected).

The risks to consumers of livestock products from these creeks is therefore assessed to be **low and acceptable**.

In addition, there are a number of other creeks on island, the catchment areas for which are located away from key source areas. These include Stockyard Creek[3] and water bodies associated with Mount Pitt (with the exception of Broken Bridge Creek). Sampling was not completed in these creeks as part of the DSI because the potential for PFAS from the identified sources to enter these creeks is assessed to be low. The risks to consumers of livestock products from these catchments (where livestock may have access to creek water for drinking) associated with PFAS from identified source areas is therefore also assessed to be **low and acceptable**.

5.7.2.2 Screening assessment for potential water sources outside Mission Creek

It is noted that even though certain livestock are understood to be present only in certain areas, the screening levels for all livestock types (where available) have been compared with all measured creek concentrations, and all measured concentrations in other potential livestock water sources, to provide an assessment of the potential risk profile if land uses change. Where no exceedances of the screening levels are identified, this will indicate that risks will remain low regardless of the livestock that may be kept.

It is recognised that some livestock may be exposed to PFAS in stock water for a limited period, while others may drink primarily this water. The screening levels assume livestock exposed via stock water may be continuously exposed, and the results of this assessment are conservatively applied for all livestock. This approach will be conservative for livestock which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water).

PFAS concentrations in creeks across the island are presented in **Figure 2**. The range in PFAS concentrations measured in potential water sources outside Mission Creek are compared to the screening levels derived for a range of different livestock type in **Table 5-6 (PFOS)** and **Table 5-6 (PFHxS)**:

[3] Within the Stockyard Creek catchment, the Ball Bay refuelling area was identified as a potential Group 2 (lower risk) source area (PS10). No surface water was identified at this location during Senversa's investigations, and only very low concentrations of PFAS in soil were identified (0.0021 – 0.0024 mg/kg PFOS, below all screening levels). On this basis, the risks to human health and the environment were assessed to be low in this location; no other sources were identified in this catchment.

Table 5-6: Comparison of PFOS concentrations measured in potential water sources outside Mission Creek to stock water screening levels

Creek	PFOS screening level (µg/L)			PFOS concentration (µg/L)		Number of samples
	Beef cattle	Sheep	Dairy Cattle	Min	Max	
Watermill Creek	0.33	1.6	1.0	<0.01	0.29	13
Cascade Creek[4]				<0.01	0.1	9
Headstone Creek				<0.01	0.02	7
Rocky Point Creek				<0.01	<0.01	2
Bore and tank water (outside Mission Creek)[5]				<0.01	0.01	19

Table 5-7: Comparison of PFHxS concentrations measured in potential water sources outside Mission Creek to stock water screening levels

Creek	PFHxS screening level (µg/L)			PFHxS concentration (µg/L)		Number of samples
	Beef cattle	Sheep	Dairy Cattle	Min	Max	
Watermill Creek	1.2	1.1	6.5	<0.02	0.85	13
Cascade Creek[6]				<0.02	0.08	9
Headstone Creek				<0.01	0.02	7
Rocky Point Creek				<0.01	0.03	2
Bore and tank water (outside Mission Creek)[7]				<0.01	0.04	19

None of the measured concentrations of PFOS or PFHxS in any of the potential water sources outside Mission Creek exceeded the screening levels for the protection of consumers of livestock products.

[4] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[5] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores and tanks on private properties, together with public / water carter supply bores. This water may also be used for stock watering, and is therefore relevant to the assessment.
[6] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[7] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores and tanks on private properties, together with public / water carter supply bores. This water may also be used for stock watering, and is therefore relevant to the assessment.

On this basis, the risks to consumers of livestock products if water from these creeks is used for watering livestock are assessed to be **low and acceptable.** The livestock types considered in this assessment are:

- Beef cattle (meat, offal, tallow, bones);
- Dairy cattle (milk or milk products); and
- Sheep (lamb or offal).

It is understood that pigs may be raised in some catchments (including Watermill Creek and Stockyard Creek). There is limited literature data on which to estimate screening levels for pigs. On this basis, when coupled with the limited information regarding where pigs might be kept and stock watering sources for these animals, further assessment has not been undertaken for pigs at this stage.

As noted in **Section 5.4.5**, the keeping of pigs is limited on island and consumption rates are likely to be generally lower than other produce types. On this basis, given that the risks from other livestock produce are assessed to be low (based on comparison to screening levels which assume high consumption rates), it is unlikely that elevated risks would be associated with the consumption of pork and other pig products. Notwithstanding this, risks cannot be fully excluded without additional information and/or assessment.

This is noted as a data gap; the requirement for further assessment/management of this pathway should be assessed as part of the PFAS Management Plan.

5.8 Screening assessment: grass in Mission Creek

5.8.1 Screening comparison

Four grass samples were collected from the dry creek bed at different locations along the creek where cattle could potentially have access to consume grass within the creek bed as a small portion of their diet at times when the creek is dry. This includes:

- Two samples from a property used to graze cattle (**Property C**, as discussed in **Section 5.7.1**) where cattle have access to drink from Mission Creek when the creek is in flow, and where concentrations in the Mission Creek water exceed stock watering screening levels.
- One sample from each of two other locations further along the course of Mission Creek where cattle grazing occurs, these include Property D (the next property down gradient of Property C) and Property E (located near the end of Mission Creek). The course of the creek crosses these properties, but no surface water was identified on any sampling visits undertaken by Senversa.

Measured concentrations in grass sampled from the bed of Mission Creek are compared with the screening level for beef cattle in **Table 5-8** below:

Table 5-8: Grass screening assessment for Mission Creek

COPC	Grass (ww) (mg/kg)					
	Grass screening level (beef cattle)	Property C			Property D	Property E
		Min	Max	Average (mean)		
PFOS	0.03	0.011	**0.034**	0.023	0.002	<0.001
PFHxS	0.1	0.003	0.007	0.005	0.002	<0.001

The results of the screening assessment are summarised below in Section 5.8.1 (property C) and Section 5.8.2 (other properties).

5.8.2 Risk Characterisation: Property C

On property C, the maximum concentration of PFOS marginally exceeds the screening level, however the average concentration of PFOS in the two samples measured in the paddock is below the screening level. Overall, given the conservatism in the screening levels, risks to consumers of produce where the cattle have access to this grass are therefore assessed as likely to be **low and acceptable**. There are a number of limitations to this assessment, discussed in **Section 5.8.4** below.

Notwithstanding these limitations, comparison with the screening assessment for water concentrations on the same property (see **Section 5.7.1**) indicates that stock watering is likely to be the driving risk pathway (as stock watering concentrations were around an order of magnitude above the screening levels), and that the consumption of grass by cattle on this property is unlikely to contribute significantly to the overall risk profile when compared with the stock watering pathway. On this basis, assessing the cumulative exposure via grass and stock water is not considered warranted, and further assessment of potential risks on this property (undertaken in **Section 5.9**) has focussed on the stock watering pathway alone as the key exposure pathway.

5.8.3 Risk Characterisation: other properties

On other properties, none of the measured concentrations exceed the screening levels (and are an order of magnitude below the screening levels); as such the risks to consumers of produce where the cattle have access to this grass are assessed to be **low and acceptable**.

The three properties sampled are assessed to cover the range of properties where cattle may have access to the creek bed in Mission Creek. Property C is the furthest property up-gradient where cattle grazing occurs, and Property D is immediately down-gradient of Property C. As only very low concentrations of PFAS in grass were identified on Property D, it is assessed based on the available data that the risks to consumers of produce where the cattle have access to this grass are likely to be **low and acceptable** on all properties down-gradient of Property D.

There are a number of limitations to this assessment, discussed in **Section 5.8.4** below.

5.8.4 Limitations and requirement for further assessment

While the risks to consumers of produce where the cattle have access to grass within Mission Creek are assessed to be low and acceptable, it is acknowledged that the available data regarding PFAS in grass within the Mission Creek bed is very limited, and that further sampling would therefore support the assessment provided above.

As such, the limited grass data along Mission Creek is identified as a data gap, and the requirement for future further assessment/management of this pathway (to provide additional confidence in the results of the assessment) should be further assessed as part of the PFAS Management Plan.

5.9 Screening assessment: grass from airport

Grass from the airport is potentially mown and used for beef cattle fodder, and therefore the risks to consumers of beef cattle where cattle are fed with grass cut from the airport have been assessed.

Twenty grass samples were collected from seventeen locations across the airport, focussing on source areas, but with some additional broader sampling across the airport. The sampling was targeted in areas of highest soil impact, with some additional sampling completed to establish the extent of any grass impact across the broader airport (away from source areas). A figure showing the location of the samples and the concentrations is presented as **Figure A13** of the DSI. As the sampling included source areas where the highest soil concentrations were measured, together with coverage of the broader airport, the dataset is considered to appropriate to assess both likely maximum grass concentrations on the airport, and also the overall concentrations. Only very low concentrations were measured:

- PFOS at the limit of reporting (LOR) (0.001 mg/kg) was identified in two locations (A_BIOTA128 (near the current drill ground), and A_BIOTA138 (near the former fire station / flushing area).
- PFOS in all other locations was below the LOR (<0.001 mg/kg).
- PFHxS was the LOR (<0.001 mg/kg) in all locations.

Measured concentrations in grass sampled from the bed of Mission Creek are compared with the screening level for beef cattle in **Table 5-8** below:

Table 5-9: Grass screening assessment for Airport

COPC	Grass (ww) (mg/kg)		
	Grass screening level (beef cattle)	Airport	
		Min	Max
PFOS	0.03	<0.001	0.001
PFHxS	0.1	<0.001	<0.001

The results of the screening assessment indicate all concentrations are at least 30 times below the screening levels. On this basis, it is assessed that the risks to consumers of beef cattle where cattle are fed with grass cut from the airport are **low and acceptable**.

There is a level of uncertainty in the grass screening level, given the uncertainty in estimating uptake into cattle. However, given the high margin of safety between the measured concentrations and the screening levels, together with the extensive sampling completed across the airport and the very low concentrations measured, confidence is maintained in the results of the assessment. This risks are assessed to be negligible, and no further assessment or management of this pathway is required.

5.10 Further assessment of potential risks from stock watering in Mission Creek catchment

5.10.1 Assessment approach

As a number of the measured PFAS concentrations in water used for stock watering on Mission Creek exceeded stock water screening levels for beef cattle, further assessment has been undertaken.

The majority of cattle on island will not be exposed to water within the Mission Creek catchment. The assessment is undertaken for those cattle utilising fenced paddocks with access to water from Mission Creek (whether through pumping, or where the creek crosses the paddock).

This approach for this further assessment is summarised below:

- Concentrations of PFAS in beef and offal have been estimated for beef cattle based on measured concentrations in stock water (see further discussion in **Section 5.10.2** regarding the estimation approach).
- Estimated PFAS concentrations in meat have been compared to the trigger points provided in FSANZ, 2017. Trigger points are defined as the maximum concentration level of these chemicals that could be present in individual foods or food groups so where even at high consumption levels, consumers of these foods would not have dietary exposures exceeding the relevant health based guidance value; the trigger points are conservative screening levels for comparison with the estimated concentrations. This assessment is broadly applicable for home consumption of beef cattle products (e.g. for someone who regularly slaughters animals raised within Mission Creek, and consumes mainly livestock products from this source).
- In addition, for meat and offal sold for islander consumption (e.g. through butcher shops), PFAS intake levels by islanders consuming these products as part of their diet (and the level of risk associated with this intake) have been estimated. This assessment takes into account purchased meat coming from a variety of sources, such that only a proportion of the total meat consumed by the general islander population would be sourced from the small number of properties sourcing their stock water from Mission Creek.

5.10.2 Limitations in the Approach

In order to estimate the level of risk to consumers of beef and offal from cows which drink water from Mission Creek, it is necessary, in the absence of measured PFAS concentrations, to estimate the concentrations of PFAS in these products.

A number of studies, including Kowalczyk, 2013, have demonstrated clear relationships between blood plasma concentrations and concentrations in milk and meat for dairy cows. This means a non-destructive test can be completed to measure PFAS concentration in cattle blood serum (or blood plasma), and then use experimentally derived factors to estimate the concentrations in meat, offal and milk from the concentrations in blood serum (or blood plasma).

Blood serum (or blood plasma) data has not been collected. It is therefore necessary to additionally estimate the concentrations in blood serum (or blood plasma), from the likely intake from stock water. This is performed by using the measured concentrations in water used for stock watering, and applying an uptake factor to estimate plasma concentrations from the estimated intake. Concentrations in meat, offal and milk are then estimated from serum concentrations using distribution factors. The derivation of the uptake and distribution factors is discussed in detail in **Appendix D**. There is a relatively high level of uncertainty in this aspect of the assessment, in particular because the animal's overall exposure is estimated, not measured.

In particular, it is noted that the uptake factors adopted in the assessment to estimate concentrations in serum from intake consider the steady-state blood serum concentrations that could be reached after longer-term continuous exposure.

This approach is broadly appropriate for cattle primarily drinking impacted stock water over the longer term, but will be conservative for cattle which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water), and are therefore exposed intermittently. Notwithstanding this, and in the absence of a robust methodology for estimating serum concentrations where cattle are exposed intermittently, the results of this assessment are conservatively applied for all cattle potentially exposed to this water, regardless of whether their exposure is continuous or intermittent. The assessment will therefore be conservative for cattle which are not continuously exposed.

5.10.3 Adopted Health Based Guidance Values

In order to assess the potential level of risk to people consuming beef cattle products, it is necessary to define a health based guidance value. In discussing the use of health based guidance value for PFAS, the Department of Health indicates the following:

> *"Health based guidance values indicate the amount of a chemical in food or drinking water that a person can consume on a regular basis over a lifetime without any significant risk to health. Health based guidance values can be expressed as a tolerable monthly intake (TMI), a tolerable weekly intake (TWI) or a tolerable daily intake (TDI). The choice of whether a TMI, TWI or TDI is set depends on the nature of the chemical. For PFOS, PFOA and PFHxS, health based guidance values are expressed as a TDI."*

A further discussion of the selected health based guidance values selected to assess the potential risks to people consuming meat, offal and milk from the Investigation Area is provided in **Section 4.0**. In summary, the assessment has adopted TDIs as defined in FSANZ (2017) and presented in the NEPM 2.0, from which background intakes are subtracted to define the tolerable intake from consumption of meat and offal.

5.10.4 Background exposure

When evaluating potential health effects for chemicals assessed on the basis of a threshold TDI, total exposure to a given chemical (i.e. the sum of the background exposure and the exposure from contaminated media) should not exceed the TDI (NEPC 2013). It is therefore necessary to estimate background exposure to PFAS compounds.

The approach followed for this HHERA to estimate background includes consideration of metrics which take into account ambient background exposure from all sources. There is limited published information on ambient background exposure to PFAS in Norfolk Island or Australia.

A review of the available data is presented below:

- Studies of pooled serum PFOS measurements from the Australian population (in southeast Queensland) have estimated that background PFOS intakes by males and females greater than 12 years of age were 0.0016±0.0003 µg/kg/day in 2002/2003, and were 0.0014 ±0.0003 µg/kg/day in 2006/2007 (Thompson et al. 2010a, 2010b). However, average serum concentrations in 2010/2011 were significantly lower (approximately 56% of those reported in 2002/2003 (Toms et al. 2014). Proportionally, the lower serum concentration would result in an estimated background intake 56% of that in 2002/2003, or approximately 0.0009 µg/kg/day.
- Using this 2010-2011 data, assuming a normal distribution, and similar statistical variability to that reported in 2002/2003 (a conservative assumption given the reduction in the absolute mean values), 97.5% of the Australian population would be predicted to have a background PFOS intake less than 0.0015 µg/kg/day (0.0009 ± two standard deviations of 0.0003).
- It is additionally noted (for comparison purposes) that estimates for mean intake above are consistent with the estimates for background intake presented in CRC CARE, 2017 (0.00089 µg/kg/day PFOS) based on the same data and methodology. The CRC CARE derivation considered these unadjusted mean values in their assessment; As these background intakes were <1% of the TDI adopted in the CRC CARE assessment (less stringent than the FSANZ TDI adopted here), background intake was not considered further in the derivation of screening levels by CRC CARE (but has been considered here, given the FSANZ TDI is lower).

- A background PFOS intake of 0.0015 µg/kg/day is therefore assumed in this HHERA. This represents 7.5% of the adopted TRV, indicating that background exposure is unlikely to contribute significantly to the estimated risks. The same background has been assumed for PFHxS.

5.10.5 Exposure assessment

The scenarios considered in the assessment are defined based on the screening assessment conducted in **Section 5.7.1,** and consider consumers of cattle products from beef cattle raised on three properties within Mission Creek, and comprise the following:

- Property A: consumers of cattle products from beef cattle raised on Property A, where pumped water from Mission Creek is used for stock watering.
- Property B: consumers of cattle products from beef cattle raised on Property B, where pumped water from Mission Creek is used for stock watering. It is noted that risks were assessed to be low and acceptable on this property based on the most recent data collected, but further assessment has been undertaken to provide clarity around the changing risk profile over multiple sampling rounds. Property C: consumers of cattle products from beef cattle raised on Property C, where cattle have direct access to Mission Creek.

The adopted concentrations in this assessment are summarised below:

Table 5-10: Stock water concentrations considered in the assessment

	Stock water concentrations (µg/L)				
COPC	Property A (water is pumped to this property)		Property B (water is pumped to this property)		Property C (cattle access Mission Creek directly)
	2020	2021	2020	2021	2021
PFOS	**1.93**	0.89	0.46	0.15	3.53
PFHxS	**1.2**	1.04	0.63	0.3	3.48

5.10.6 Estimation of cattle intake

The daily PFAS intake by cattle has been estimated from the measured concentrations water by using literature data for ingestion rates water. These ingestion parameters, together with justification for the adopted ingestion rates is provided in **Appendix E.**

It is noted that this assessment conservatively assumes that cattle are continuously exposed to PFAS-affected stock water. Cattle may move around to different pastures, or have access to other water sources, in which case this assumption is conservative. This conservative approach is adopted because some cattle may spend most of their time with access to the Mission Creek water sources.

5.10.7 Estimation of concentrations in serum, meat and offal

Concentrations in blood serum are estimated using the measured concentrations in water used for stock watering, and applying an uptake factor to estimate plasma concentrations from the estimated intake. Concentrations in meat, offal and milk are then estimated from serum concentrations using distribution factors. The derivation of the uptake and distribution factors is discussed in detail in **Appendix D**.

The calculation of the estimated concentrations for each scenario is presented in **Appendix E**.

5.10.8 Risk characterisation: home consumption

In order to assess the risk to local home-consumers of meat and offal, estimated concentrations have been compared to FSANZ trigger values for mammalian meat and mammalian offal. Trigger values are defined as the maximum concentration level of these chemicals that could be present in individual foods or food groups so where even at high consumption levels, consumers of these foods would not have dietary exposures exceeding the relevant health based guidance value; the trigger values are conservative screening levels for comparison with the estimated concentrations.

It is noted that the assessment assumes cattle are continuously exposed to PFAS in their stock water. This approach is broadly appropriate for cattle primarily drinking impacted stock water over the longer term, but will be conservative for cattle which source water from a variety of sources (e.g. through visiting different pastures, or supply with supplementary water), and are therefore exposed intermittently. Notwithstanding this, the results of this assessment are conservatively applied for all cattle potentially exposed to this water, regardless of whether their exposure is continuous or intermittent.

The results are presented in **Appendix E** and summarised below:

Table 5-11: Risk assessment for home consumption

		Property A (water is pumped to this property)		Property B (water is pumped to this property)		Property C (cattle access Mission Creek directly)
		2020	2021	2020	2021	2021
Meat FSANZ trigger: 3.5 µg/kg (PFOS+PFHxS)	Estimated PFOS+PFHxS concentration in meat	**24**	**13**	**6.8**	2.5	**48**
	Potentially elevated risk?	**Yes**	**Yes**	**Yes**	No	**Yes**
Meat FSANZ trigger: 96 µg/kg (PFOS+PFHxS)	Estimated PFOS+PFHxS concentration in offal[8]	**460**	**220**	**110**	38	**850**
	Potentially elevated risk?	**Yes**	**Yes**	**Yes**	No	**Yes**

The results of the assessment indicate the following:

Property A

- The risks to home consumers of cattle products from Property A are assessed to be **potentially elevated** based on both the 2020 and 2021 water concentrations, and estimated concentrations are around 5 – 10 times above the acceptable level for regular consumers of produce from this property.
- This assessment is based on estimating the concentrations in mean, liver, and kidney. The risks to consumers of other cattle products (e.g. tallow, bones used for stock) are likely to be lower than for consumers of meat and offal (as discussed in **Appendix B**) but given that estimated concentrations in meat and offal are 5 – 10 times above the acceptable level, risks to consumers of these products are also assessed to be **potentially elevated** on a comparative basis.

[8] Concentrations have been estimated in liver and kidney. The higher of these (the liver concentration) is provided here

Property B

- The risks to home consumers of cattle products from Property B are assessed to be **potentially elevated** based 2020 water concentrations, but **low and acceptable** based on the more recent 2021 water concentrations.
- This assessment is based on estimating the concentrations in mean, liver, and kidney. The risks to consumers of other cattle products (e.g. tallow, bones used for stock) are likely to be lower than for consumers of meat and offal (as discussed in **Appendix B**). As estimated concentrations in meat and offal are only marginally above acceptable levels (2020) or below (2021), risks to consumers of these products are assessed to be **low and acceptable** on a comparative basis.

Property C

- The risks to home consumers of cattle products from Property C are assessed to be **potentially elevated**, and estimated concentrations are around 10 times above the acceptable level for regular consumers of produce from this property.
- This assessment is based on estimating the concentrations in mean, liver, and kidney. The risks to consumers of other cattle products (e.g. tallow, bones used for stock) are likely to be lower than for consumers of meat and offal (as discussed in **Appendix B**) but given that estimated concentrations in meat and offal are approximately 10 times above the acceptable level, risks to consumers of these products are also assessed to be **potentially elevated** on a comparative basis.

It is emphasised that the home consumption assessment considers someone who regularly slaughters animals raised within Mission Creek, and consumes mainly livestock products from this source. Most people potentially consuming these livestock products will be exposed much less frequently, and their risk will be lower. Reference should be made to **Section 5.9.8** for an assessment of the risks to public consumers (e.g. people who consume island-raised beef purchased from the butcher).

5.10.9 Limitations and requirement for further assessment: home consumers

Based on the currently measured concentrations, risks to home consumers are assessed to be **potentially elevated** for Property A and Property C, but **low and acceptable** for Property B.

The assessment is likely to be conservative, in particular as it assumes continuous exposure of cattle to PFAS in the water they drink. Notwithstanding this, there is a relatively high level of uncertainty in the assessment, given the uncertainties associated with estimating concentrations in livestock products from concentrations in stock water, and also because the assessment is based on limited data regarding the concentrations in water. For the property where the highest concentrations are measured in water used for stock watering, only one sampling round has been conducted.

On this basis, and noting that the estimated concentrations are up to around ten times above the acceptable level for people regularly consuming the produce, it is assessed that further assessment and/or management is required (as part of subsequent management works) for a pathway of home consumption of beef cattle products from these properties where cattle may have access to water from Mission Creek.. These works should be completed as part of the PFAS Management Plan.

5.10.10 Risk characterisation: public consumption

To assess the risk for public consumers, the distribution into the broader island market requires consideration.

Cattle from paddocks with access to water from Mission Creek which are not raised for home consumption will be sold through local butchers or will be used in restaurants (primarily tourist consumption).

- Few local people would eat local beef every day, due to limited availability. Approximately 20 – 30 % of the beef sold by butchers on island is local (island-reared) beef, and much of this goes to the tourist / restaurant trade. The remainder of beef consumed on island is imported, and there are sometimes periods where no local beef is available for sale.

- Only a small proportion of the local beef raised on island will come from the Mission Creek properties where cattle may be exposed to PFAS via stock water. While the exact number of cattle which may be present on these properties is likely to be variable, cattle from these properties are likely to make up less than 10% of the total local beef sold in the butchers on island.
- Considering together the small proportion of on-island beef likely to be sourced from these Mission Creek properties (20 – 30%), together with the small proportion of consumed beef being local beef (raised on-island) , assumed as <10%, it is conservatively assessed that at most, 5% of the total beef cattle products consumed by islanders purchasing from the butcher could be sourced from these properties which source water from Mission Creek.
- The risk from tourist exposures is assessed to be negligible, given the absence of chronic exposure and the potential for only a small number of serves to be consumed. The risk to tourists has not been assessed further.

Based on these estimated intakes, the risks to health for public consumption were estimated by direct comparison of the daily chemical intake for each COPC with its respective tolerable daily intake (TDIs) as defined in FSANZ (2017), from which background intakes are subtracted to define the tolerable intake from consumption of meat and offal.

The ratio of intake to acceptable intake is referred to as the hazard quotient (HQ)[9]. A potentially unacceptable chemical intake/exposure is indicated if the HQ is greater than 1.

The derivation of the HQs is presented in **Appendix E and the results are** summarised below:

Table 5-12: Risk assessment for public consumption

		Property A (water is pumped to this property)		Property B (water is pumped to this property)		Property C (cattle access Mission Creek directly)
		2020	2021	2020	2021	2021
Meat	**HQ[10]**	0.11	0.06	0.032	0.012	0.23
	Potentially elevated risk?	No	No	No	No	No
Offal	**HQ[11]**	0.51	0.24	0.13	0.042	0.95
	Potentially elevated risk?	No	No	No	No	No

[9] The Hazard Quotient (HQ) is defined as follows:

$$HQ = \frac{CDI}{TDI - background}$$

Where:

HQ	=	Hazard Quotient (unitless)
CDI	=	Chronic Daily Intake (mg/kg/day)
TDI	=	Tolerable Daily Intake (mg/kg/day)

[10] Risks from meat consumption have been estimated for both adults and children. The HQ presented here is the higher of the two.

[11] Risks from offal consumption have been estimated in liver and kidney. The higher of these (the risks associated with liver consumption) is provided here

The results of the assessment indicate that for all three properties:

- The risks to public consumers of cattle products from these properties are assessed to be **low and acceptable** based on both the 2020 and 2021 water concentrations.
- This assessment is based on estimating the concentrations in meat, liver, and kidney. The risks to consumers of other cattle products (e.g. tallow, bones used for stock) are also assessed to be **low and acceptable** on a comparative basis, as discussed in **Appendix B**.

5.10.11 Limitations and requirement for further assessment: public consumers

Based on the currently measured concentrations, risks to public consumers associated with the consumption of cattle products from those properties where cattle may have access to water from Mission Creek are assessed to be **low and acceptable**. It is emphasised that there are no regulatory restrictions with respect to PFAS in livestock products (including cattle products) and that, currently, there are no regulated maximum limits for PFAS in any foods in Australia or overseas[12] but research is ongoing.

The assessment is likely to be conservative, in particular as it assumes continuous exposure of cattle to PFAS in the water they drink. Notwithstanding this, there is a relatively high level of uncertainty in the assessment, given the uncertainties associated with estimating concentrations in livestock products from concentrations in stock water, and also because the assessment is based on limited data regarding the concentrations in water. For the property where the highest concentrations are measured in water used for stock watering, only one sampling round has been conducted.

On this basis, it is recommended that further assessment and/or management is required for the public consumption of cattle products from those properties where cattle may have access to water from Mission Creek. It is noted that further assessment and/or management is also required for home consumers, for whom the potential for exposure is greater (as discussed in **Section 5.9.7**). These works should be completed as part of the PFAS Management Plan.

5.11 Livestock Health

5.11.1 Background and approach

In addition to assessing the potential risks to people consuming livestock products, consideration has been given to the potential impact of PFAS exposure on livestock health.

The clearest indicator of PFAS exposure and potential risk is the blood plasma concentration. In line with the methodology used to define health based guidance values for humans (as presented in FSANZ, 2017a[13]), the effect on an animal is proportional to the blood plasma concentration, and it is generally assumed that the same blood plasma concentration will produce similar effects in different species. On this basis, it is considered that blood plasma concentrations at which adverse effects are not identified in one species would be also expected to have no adverse effect in a different species.

In order to assess potential risks to livestock health, the estimated concentrations in cattle blood plasma have therefore been compared to blood plasma concentrations at which adverse effects were not identified in experimental studies (in other species or in livestock).

5.11.2 Measured and estimated cattle blood plasma concentrations in the Investigation Area

Cattle blood plasma concentrations were estimated as part of the risk assessment of human consumption of beef cattle products. Concentrations were estimated for cattle in Mission Creek exposed to PFAS in stock water.

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[12] SAFEMEAT, 2019. Issues brief: LPA and per- and polyfluoroalkyl substances (PFAS). Available from the Australian Government PFAS information portal (https://www.pfas.gov.au/audience/business)

[13] FSANZ, 2017a. *Hazard assessment report – Perfluorooctane Sulfonate (PFOS), Perfluorooctanoic Acid (PFOA), Perfluorohexane Sulfonate (PFHxS)*

This is considered to represent the scenario with the highest potential for PFAS exposure on island, with much lower PFAS concentrations measured outside of Mission Creek. As such, the blood plasma concentrations associated with the exposure of livestock (e.g. cattle, sheep, pigs) and other non-livestock animals (e.g. horses) in other catchments would be expected to be lower than those estimated for this scenario.

The estimated serum concentrations for beef cattle exposed via stock water in Mission Creek are presented in **Appendix E**. In summary, the estimated blood plasma concentrations are in the following ranges:

- PFOS: 20 – 510 µg/L.
- PFHxS: 20 – 230 µg/L.

The assessment of risk to livestock health has focussed on PFOS, as PFHxS is considered unlikely to contribute significantly to livestock health risks, for the following reasons:

- Estimated PFOS serum concentrations are around 10 times higher than PFHxS concentrations.
- In line with FSANZ, 2017a, and in the absence of sufficient toxicity data to develop a health based guidance value specifically for PFHxS, PFHxS is conservatively assessed using the toxicity data for PFOS. The conclusion that PFOS has a higher toxicity than PFHxS is considered to hold across different species groups.

On this basis, in order to assess risks to livestock health, the measured and estimated range of PFOS in cattle blood serum (20 – 510 µg/L) has been compared below to blood plasma concentrations at which adverse effects were not identified in experimental studies (in other species or in livestock).

5.11.3 Experimental study data

In deriving the (human) health based guidance value for PFOS, FSANZ (2017a) considered the following experimentally-derived no-observed-adverse-effect-levels (NOAELs)[14] in experimental animals:

Table 5-13: Animal NOAELs from experimental toxicity studies

Study	NOAEL blood plasma concentration (µg/L)
Seacat et al. 2002; monkey	38,100
Butenhoff et al. 2012/Thomford 2002; male rat	8,650
Butenhoff et al. 2012/Thomford 2002; female rat	4,600
Thibodeaux et al. 2003/Lau et al. 2003; female rat	15,600
Luebker et al. 2005b; female rat	7,140

As the estimated livestock blood plasma concentrations (20 – 510 µg/L) are below this range in NOAELs, it is assessed anticipated that risks to livestock health will be low and acceptable.

In addition, while not designed as toxicity studies, it is noted that health effects were not observed in the following studies[15] in livestock at the maximum observed blood plasma concentrations (some of which could be far below the concentrations at which health effects could be expected):

[14] NOAELs (no-observed-adverse-effect-levels) are defined as the highest concentrations identified in the study at which no adverse effects were observed.
[15] Each of the cattle studies is discussed in more detail in **Appendix D** (where cattle uptake factors are derived); the Kowalczyk, 2012 sheep study is discussed above in **Section 6.10**.

Table 5-14: Intakes not noted to be associated with health effects in livestock animals

Study	Maximum blood plasma concentration (µg/L)
Kowalczyk, 2013 – dairy cows	2,200
Lupton, 2014 – beef cattle	52,600
Lupton, 2015 – beef cattle	71,500
Kowalczyk, 2012 – sheep	240
Drew, 2021 – beef cattle	1,944

5.11.4 Conclusions of health assessment for livestock and other animals

It is concluded that the risks to cattle health for cattle exposed via stock water in Mission Creek are **low and acceptable** because estimated blood plasma PFOS concentrations in cattle (20 – 510 µg/L) are markedly below serum levels which have not been associated with any adverse effects, in both stock (including cattle and sheep) and experimental animals (including monkeys and rats and mice).

By extension, risks are also assessed to be **low and acceptable** for both livestock (e.g. cattle, sheep, pigs) and other non-livestock animals (e.g. horses) in catchments outside Mission Creek, because exposure to cattle in the Mission Creek catchment is considered to represent the scenario with the highest potential for PFAS exposure on island, with much lower PFAS concentrations measured outside of Mission Creek. As such, the blood plasma concentrations associated with the exposure of livestock and other animals outside Mission Creek (and therefore the risks to health) would be expected to be lower.

6.0 Risk assessment for fruit and vegetables

6.1 Issues identification

6.1.1 Use of water for irrigation

Irrigation water is used across the island for small commercial and private residential gardens. CSIRO estimated approximately 10.8 hectares of cultivated land is used for commercial food production, up to 75% of which may be irrigated. An additional 5 hectares of land is estimated to be used for medium to large scale vegetable gardens, it is unknown to what extent these gardens are irrigated. The source of irrigation water is known for some properties, but is across the broader island. Water used is expected to be predominantly bore water or pumped from surface water bodies, based on anecdotal evidence provided during the investigation and sampling works.

PFAS impacts have been reported in water from a number of creeks and other water sources on-island, with the highest concentrations measured in Mission Creek. Some of this water may be used for irrigation of fruit and vegetables on some properties. Where PFAS is present in water which may be used for irrigation, there is the potential for PFAS in water to be taken up into produce and for exposure to subsequently occur to people consuming the produce.

In the DSI, this pathway was assessed further through biota (fruit and vegetable) sampling at a private property (ID013) on Mission Creek where water impacted with PFAS was known to be used for irrigation, and where produce is grown for both home consumption and sale. Key information regarding this sampling summarised as follows:

- There were two properties within the Mission Creek catchment where produce irrigation has been identified to occur.
  - At property ID013, the water is understood to be sourced from Mission Creek and elevated concentrations of PFAS were identified in the water (2-3 µg/L PFOS+PFHxS).
  - At property ID016, bore water used for produce irrigation was sampled. PFAS concentrations in this water were much lower than at ID013 (0.14 µg/L PFOS+PFHxS).
- PFAS concentrations in Mission Creek catchment are generally much higher than elsewhere on island; the potential exposures on ID013 are considered to represent the high-end exposure on island, with exposures on other properties (including ID016 within Mission Creek, and properties in other catchments) assessed to be lower.
- A broad range of produce was sampled, including pawpaw, mango, capsicum, basil, chives and parsley. This represented the range of produce watered with water from Mission Creek at property ID013 the time of sampling. From the land use survey conducted with the landholder, there are no other known produce types grown at this property at other times of the year and potentially watered with water from Mission Creek. Produce types are effectively constant year round in the climate, although at times of drought there will be no water in Mission Creek and therefore very limited produce grown using this water for irrigation. The sampling was undertaken outside drought conditions. The range of produce types assessed is consistent with the range grown.
- PFOS concentrations in all biota were below laboratory limit of reporting (LOR), therefore the risk is considered to be low and acceptable at this property. **Further consideration has been given to below to how variation in concentrations of PFAS within the irrigation water (within the currently observed range) might impact upon this conclusion.**
- Risks are inferred to be low for other properties (including ID016 within Mission Creek, and properties in other catchments) where concentrations are lower but these risks were not fully excluded in the DSI. **A pathway of produce consumption where produce is irrigated with creek/bore water from other catchments has been further assessed here for completeness.**

6.1.2 Produce grown in creek beds

In addition to this irrigation pathway, there are noted to be sediment concentrations above the HIL-A in sediments from Mission Creek (multiple samples) and Cascade Creek (one localised, marginal exceedance (in a primary and duplicate sample collected at the same location)). There are no exceedances of the HIL-A in other creeks, or in soils sampled from residential areas where produce may be grown, with the exception of ID013 (the property discussed above, where risks have been assessed through biota sampling).

- An interview with the landholder where the impacts were identified in Cascade Creek indicated that mint and guava grow in the creek bed near where the sediment impact was identified, and are sometimes consumed (although the volumes consumed are low). **This pathway is assessed further in the HHERA for completeness.**
- Interviews with landholders through the Mission Creek catchment have indicated no known growing of home produce within the creek bed of Mission Creek; this pathway is therefore not considered further
- It is unknown if produce grown in creek beds of other catchments is consumed. However, as sediment concentrations in other creeks were below the HIL-A, the risks associated with this pathway (should it be active) are assessed to be low and acceptable

6.2 Approach

For the irrigation pathway, the range in creek and bore concentrations away from property ID013 (including one other property from the Mission Creek catchment where irrigation occurs, and concentrations in other catchments) has been compared with the concentrations in irrigation water from property ID013 to provide a comparative assessment.

In addition (to account for the potential that other produce types could be grown at other properties), conservative irrigation water screening levels have been derived and compared with creek water concentrations to provide an additional line of evidence regarding the risks to consumers of produce irrigated with creek/bore water across the island.

For produce grown in creek beds, refined screening levels have been developed for comparison with the sediment concentrations measured in Cascade Creek in exceedance of the HIL-A.

6.3 Irrigation assessment for properties other than ID013

6.3.1 Comparative assessment

Concentrations in potential irrigation water sources across the island (other than ID013) are compared with the concentrations in irrigation water from property ID013 below:

Table 6-1: Comparison of PFOS and PFHxS concentrations across catchments

Potential irrigation water source	PFOS concentration (µg/L)		PFHxS concentration (µg/L)		Number of samples
	Min	Max	Min	Max	
Irrigation water from ID013 (Mission Creek catchment)	**1.38**	**2.78**	**1.46**	**1.72**	**2**
Irrigation water from ID016 (Mission Creek catchment)	<0.01		0.14		1
Watermill Creek	<0.01	0.29	<0.02	0.85	13
Cascade Creek[16]	<0.01	0.1	<0.02	0.08	9
Headstone Creek	<0.01	0.02	<0.01	0.02	7
Rocky Point Creek	<0.01	<0.01	<0.01	0.03	2
Bore and tank water (outside Mission Creek)[17]	<0.01	0.01	<0.01	0.04	19

PFAS concentrations in creeks across the island are presented in **Figure 2**. All concentrations from creeks other than Mission Creek, and from ID016 (the only other property in the Mission Creek catchment where bore/creek water is identified to be used for produce irrigation) are significantly lower than those measured in the irrigation water from ID013. Given that a wide range of irrigated produce was sampled at ID013, and all produce concentrations were below the laboratory limit of reporting (LOR) the risks associated with produce irrigation in catchments other than Mission Creek are assessed to be low and acceptable.

6.3.2 Screening assessment

Appendix F presents the derivation of conservatively defined screening levels for pathways of fruit irrigation and vegetable irrigation.

These screening levels are defined as the concentration in water which is estimated to result in the trigger points for fruit and vegetables provided in FSANZ, 2017. Trigger points are defined as the maximum concentration level of these chemicals that could be present in individual foods or food groups so where even at high consumption levels, consumers of these foods would not have dietary exposures exceeding the relevant health based guidance value. This means the screening levels below are highly conservative, as they are derived on the basis that 100% of an individual's fruit or vegetable intake comes from the source.

[16] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[17] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores and tanks on private properties, together with public / water carter supply bores. This bore water may also be used for irrigation, and is therefore relevant to the assessment.

These screening levels are presented in **Table 6-2** below:

Table 6-2: Irrigation screening levels

Produce type	Irrigation water screening level (µg/L)	
	PFOS	PFHxS
Fruit	20	10
Vegetables	1.4	0.8

Concentrations in potential irrigation water sources across the island (other than ID013) are compared with these screening levels in Table 6-3 (PFOS) and Table 6-4 (PFHxS) below:

Table 6-3: Comparison of PFOS concentrations measured in potential water sources other than at ID013 to irrigation screening levels

Water source	PFOS screening level (µg/L)		PFOS concentration (µg/L)		Number of samples
	Fruit	Vegetables	Min	Max	n
Irrigation water from ID016[18] (Mission Creek catchment)	20	10	<0.01		1
Watermill Creek			<0.01	0.29	13
Cascade Creek[19]			<0.01	0.1	9
Headstone Creek			<0.01	0.02	7
Rocky Point Creek			<0.01	<0.01	2
Bore and tank water (outside Mission Creek)[20]			<0.01	0.01	19

[18] Produce grown at the property includes avocados, tomatoes, herbs, bananas and ice cream beans (*Inga edulis*)
[19] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[20] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores and tanks on private properties, together with public / water carter supply bores. This bore water may also be used for irrigation, and is therefore relevant to the assessment.

Table 6-4: Comparison of PFHxS concentrations measured in potential water sources outside Mission Creek to irrigation screening levels

Creek	PFHxS screening level (µg/L)		PFHxS concentration (µg/L)		Number of samples
	Fruit	Vegetables	Min	Max	n
Irrigation water from ID016[21]	1.4	0.8	0.14		1
Watermill Creek			<0.02	**0.85**	13
Cascade Creek[22]			<0.02	0.08	9
Headstone Creek			<0.01	0.02	7
Rocky Point Creek			<0.01	0.03	2
Bore and tank water (outside Mission Creek)[23]			<0.01	0.04	19

PFAS concentrations in creeks across the island are presented in **Figure 2**. None of the measured concentrations exceeded the screening levels, with the exception of the maximum PFHxS concentration in Watermill Creek (0.85 µg/L in TC_SW06, located near the airport) which marginally exceeds the screening level for vegetables (0.8 µg/L) but is below the screening level for fruit. The identified exceedance is localised, and the next highest PFHxS concentration in Watermill Creek is 0.23 µg/L, roughly 4 times below the screening level.

The high level of conservatism in the screening level is emphasised. The screening level assumes high-end consumption rates, and also assumes that 100% of an individual’s vegetable intake comes from the source irrigated with this water. It is not considered plausible that a residential user in this area would consume 100% of their vegetable intake as home produce irrigated with this localised creek source. Given the very marginal and localised nature of the exceedance, and the conservatism in the screening level, the risks to consumers of produce irrigated with creek/bore water across the island are assessed to be **low and acceptable.**

[21] Produce grown at the property includes avocados, tomatoes, herbs, bananas and ice cream beans (*Inga edulis*)
[22] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[23] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores and tanks on private properties, together with public / water carter supply bores. This bore water may also be used for irrigation, and is therefore relevant to the assessment.

6.4 Variation of concentrations over time at property ID013

A wide range of produce (fruit and vegetables) was sampled from property ID013 in 2021, and PFAS was not detected in any of the samples above the laboratory limit of reporting (i.e. PFOS+PFHxS = <0.002 mg/kg in all samples). Based on these results, the risks were assessed to be low and acceptable.

However, the irrigation water concentrations at this property varied between the two monitoring visits completed by Senversa (in 2020 and 2021). Water concentrations were approximately **60% lower** during sampling undertaken in 2021 (when produce sampling was undertaken) when compared with the results measured in 2020 (no produce sampling); with the results compared in Figure 7-2 below:

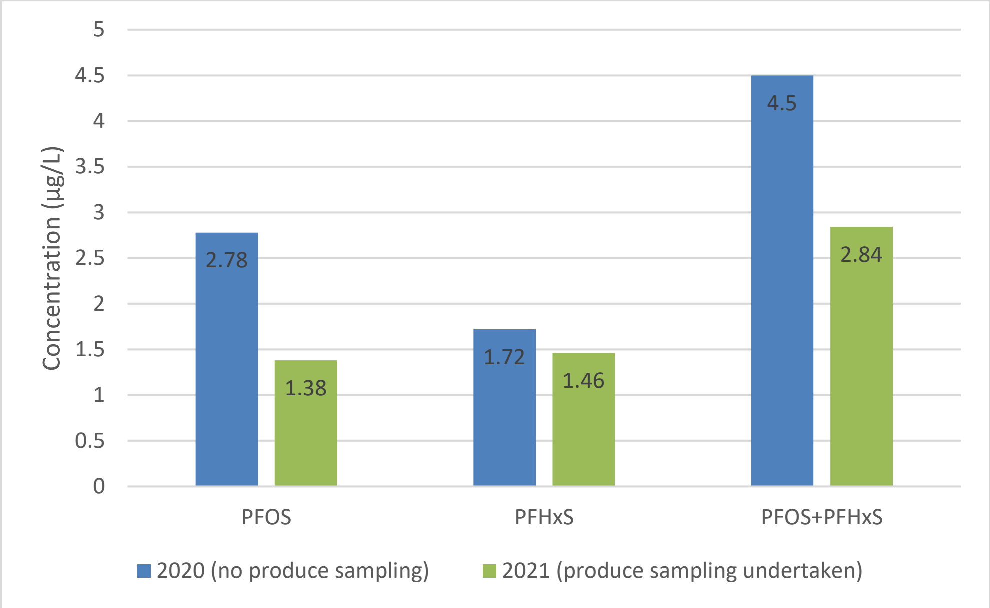


Figure 6-1: Variation in irrigation water concentration over time

It is unknown whether the reduction in water concentrations between 2020 and 2021 represents a downward trend or simply variability. As part of the PFAS Management Plan, further monitoring should be conducted to determine the long-term trend in water concentrations within Mission Creek. Based on the currently available information, it cannot be excluded that water concentrations may vary above those measured at the time of produce sampling. Consideration has therefore been given to whether variation of irrigation water concentrations (within the currently observed range) could impact upon the risk profile:

- Fruit:
  - The higher concentrations measured in 2020 (2.78 µg/L PFOS, 1.72 µg/L PFHxS) remain substantially (5 – 10 times) below the conservative irrigation screening levels developed for fruit in Section 6.3.2 (20 µg/L PFOS, 10 µg/L PFHxS).
  - Confidence is maintained that risks would remain **low and acceptable** should irrigation concentrations vary within the observed range

- Vegetables:
  - While the higher concentrations measured in 2020 (2.78 µg/L PFOS, 1.72 µg/L PFHxS) exceed the conservative irrigation screening levels developed for vegetables in Section 6.3.2 (1.4 µg/L PFOS, 0.8 µg/L PFHxS) by approximately a factor of two, these screening levels are conservative, as they are based on conservative assumptions regarding uptake into produce. Assessing risks based on measured produce concentrations is the preferred approach. This is because produce concentrations provide a measure of the actual concentrations resulting from irrigation, and remove the uncertainties associated with estimating uptake.
  - PFAS was not detected in any vegetable samples collected in 2020 (i.e. PFOS+PFHxS = <0.002 mg/kg in all samples). This indicates that risks are likely to remain **low and acceptable**, even with some variability in the irrigation water concentrations.

Notwithstanding these conclusions, monitoring of Mission Creek concentrations over time should be completed as part of the PFAS Management Plan. If concentrations higher than those currently measured are identified, this could result in changes to the risk profile, and may require a review of the risk assessment presented here.

6.5 Assessment for produce grown in creek beds

Appendix G presents the derivation of health investigation levels (HILs) for a pathway of low-density residential use (including growing of home produce). This HIL is based on the HIL A for low density residents presented in the PFAS NEMP. The derivation of the HIL values in the NEMP is described in the following document:

- State of NSW and Office of Environment and Heritage (NSWOEH), 2019: *Human health soil screening criteria for PFOS, PFHxS and PFOA: Calculation protocols and draft values for potential inclusion in the PFAS National Environmental Management Plan.*

The HILs derived here are derived **identically** to the NEMP 2.0 screening level for low-density residential use (0.01 mg/kg) which was adopted in the DSI (i.e. the derivation utilises the same assumptions and compound-specific transfer factors as detailed in NSWOEH (2019)), but rather than being derived for PFOS+PFHxS, they are derived separately for PFOS and PFHxS.

The NEMP screening level assumes equal concentrations of PFOS and PFHxS in soil; but application of separate screening levels is considered more appropriate given these compounds have different plant transfer factors. Specifically, the assumption of equal concentrations of PFOS and PFHxS is not appropriate for the identified sediment impacts in Cascade Creek, where the majority of the identified impact is PFOS.

Furthermore, it is noted that (in line with the NEMP HIL derivations) the HILs allow for 80% of the allowable PFAS intake to be via other pathways (such as via drinking water) and only 20% of the allowable exposure to be via produce ingestion pathways. This conservative approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the HIL, exposures via this pathway contribute negligibly to risk.

These screening levels are compared to the relevant Cascade Creek sediment concentrations[24] in **Table 6-2** below:

Table 6-5: Screening levels for low-density residential use (including home-grown produce) compared with Cascade Creek sediment concentrations

	Concentration (mg/kg)	
	PFOS	PFHxS
Screening level	**0.04**	**0.006**
ID012_SD01	0.0167	0.0041
ID012_SD01 (duplicate sample)	0.0195	0.006

The measured concentrations are below the screening levels, indicating that the risks are **low and acceptable**. It is emphasised that the screening levels are highly conservative, as they assume that 10% of produce consumed by a resident is from this impacted source; however the location is remote and not easily accessible, and only occasional consumption of mint and guava occurs from this location.

Furthermore it is noted that (in line with the NEMP HIL derivations) the HIL derived for intrusive workers allows for 80% of the allowable PFAS intake to be via other pathways (such as via drinking water and food) and only 20% of the allowable exposure to be via soil contact pathways. This conservative approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water, or consumption of produce into which PFOS+PFHxS has bioaccumulated). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the HIL, exposures via this pathway contribute negligibly to risk.

On this basis, the overall potential exposures to consumers of produce from this location are assessed to be negligible, and further consideration of the contribution this pathway may make to cumulative exposures is not considered warranted.

[24] The relevant concentrations represent the only sediment concentrations outside Mission Creek identified above the HIL-A adopted in the DSI. Mint and guava grow in the creek bed near where the sediment impact was identified, and are sometimes consumed

7.0 Risk assessment for chicken eggs

7.1 Issues identification

PFAS impacts have been reported in water from a number of creeks and other potential water sources on-island, with the highest concentrations measured in Mission Creek. Water is potentially used for watering chickens on some properties. Where PFAS is present in water used for watering chickens, there is the potential for PFAS in water to be taken up into chicken eggs and for exposure to subsequently occur to people consuming these eggs.

In the DSI, this pathway was assessed further through egg sampling at the private property (ID013) on Mission Creek where water containing PFAS was known to be used for watering chickens, and where eggs from the property may be sold (in small numbers) or kept for home consumption. Key information regarding this sampling summarised as follows:

- This is the only property in Mission Creek catchment where the watering of chickens with PFAS impacted water has been identified. Given that PFAS concentrations in Mission Creek catchment are much higher than elsewhere on island, the potential exposures on this property are considered to represent the high-end exposure on island, with exposures on properties in other catchments assessed to be lower.
- There are several small chicken coops on the property, but only one coop (with 8-10 chickens) where the chickens are watered with water impacted by PFAS:

Figure 7-1: Chicken coop where chickens are watered with water from Mission Creek

- The driving pathway is considered to be via drinking water. No sources were identified on the site, and PFAS concentrations in soil were low. It is also inferred that PFAS intake via diet (e.g. invertebrates) would be low, given the absence of identified soil sources which could result into uptake into soil invertebrates.

- The concentration of PFOS+PFHxS in a single egg sampled from this coop (0.009 mg/kg) was marginally below the adopted screening level (0.011 mg/kg). On the basis of this single sample, the risks to consumers of eggs are low and acceptable. However, it was noted that the result is only marginally below the trigger point, and the data is very limited. The results are considered further here to assess the requirement for further assessment and/or management.
- Risks are inferred to be low for properties in other catchments (where concentrations are lower) but were not fully excluded in the DSI. A pathway of chicken egg consumption where chickens are watered with creek/bore water from other catchments has been further assessed here for completeness.

7.2 Further assessment for chickens in Mission Creek

The measured concentration of PFOS+PFHxS in one egg sampled from a chicken watered with water containing PFAS (0.009 mg/kg) was marginally below the FSANZ trigger point[25] (0.011 mg/kg). On the basis of this single sample, the risks to consumers of eggs are low and acceptable. However, the result is only marginally below the trigger point, and the data is very limited (one sample). Further consideration has been given to the potential for higher concentrations to occur than have been currently measured:

- **Variation between eggs exposed to a single source:** It is not possible to estimate the potential variation in egg concentrations for chickens exposed to the same source on the basis of one sample, although it would be expected that some variation would occur. Given that the available result is only marginally (20%) below the screening level it cannot be excluded that concentrations above the trigger point could be present, resulting in a **potentially elevated risk**.
- **Variation over time:** the water concentrations to which the chickens are potentially exposed are variable over time. Water concentrations were approximately **60% lower** during sampling undertaken in 2021 (when egg sampling was undertaken) when compared with the results measured in 2020 (no egg sampling); with the results compared in **Table 7-1** below.

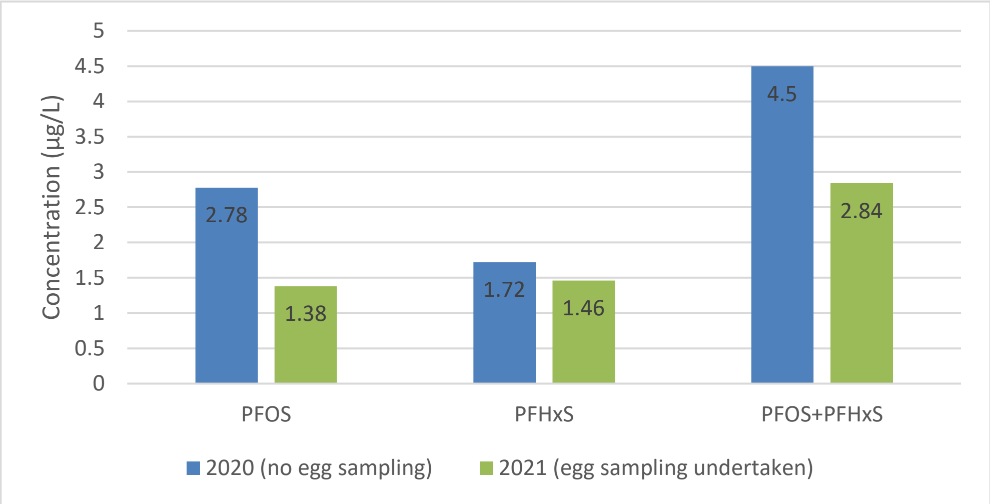


Figure 7-2: Variation in chicken drinking water concentration over time

[25] Trigger points are provided in FSANZ, 2017 and are defined as the maximum concentration level of these chemicals that could be present in individual foods or food groups so where even at high consumption levels, consumers of these foods would not have dietary exposures exceeding the relevant health based guidance value; the trigger points are conservative screening levels for comparison with the estimated concentrations. This assessment is broadly applicable for home consumption of beef cattle products (e.g. for someone who regularly slaughters animals raised within Mission Creek, and consumes mainly livestock products from this source).

- It is unknown whether the reduction in water concentrations between 2020 and 2021 represents a downward trend or simply variability. Further monitoring should be conducted as part of the PFAS Management Plan to determine the long-term trend in water concentrations within Mission Creek. Based on the currently available information, it cannot be excluded that water concentrations may vary above those measured at the time of egg sampling. Given that the available egg sampling result is only marginally (20%) below the screening level it cannot be excluded that variation in the water concentrations could result in egg concentrations above the trigger point, resulting in a **potentially elevated risk**.

The trigger point is assessed to be conservative, as it assumes 90th percentile consumption rates, and also assumes that all eggs consumed are from this source. It is unlikely that a public consumer of eggs would purchase all eggs consumed from this one small coop. This would reduce the risk to public consumers. It is also unlikely that a home consumer would source all eggs from this coop, given that multiple chicken coops are present on the property.

Notwithstanding this conservatism, however, there is assessed to be sufficient uncertainty in the assessment, such that risks are assessed to be **potentially elevated** and additional assessment and/or management is required. These works should be completed at part of the PFAS Management Plan.

7.3 Assessment for chickens outside Mission Creek

7.3.1 Comparative assessment

Concentrations in potential water sources across the island (other than Mission Creek) are compared with the concentrations in water used to water chickens from property ID013 below:

Table 7-1: Comparison of PFOS and PFHxS concentrations across catchments

Potential irrigation water source	PFOS concentration (µg/L)		PFHxS concentration (µg/L)		Number of samples
	Min	Max	Min	Max	
Water from ID013 used to water chickens	**1.38**	**2.78**	**1.46**	**1.72**	**2**
Watermill Creek	<0.01	0.29	<0.02	0.85	13
Cascade Creek[26]	<0.01	0.1	<0.02	0.08	9
Headstone Creek	<0.01	0.02	<0.01	0.02	7
Rocky Point Creek	<0.01	<0.01	<0.01	0.03	2
Other potential water sources (outside Mission Creek)[27]	<0.01	0.01	<0.01	0.04	19

[26] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[27] Water sampling outside Mission Creek as part of the DSI also included sampling of a number of bores, outdoor taps and tanks on private properties, together with public / water carter supply bores. This water may also be used for watering chickens, and is therefore relevant to the assessment.

PFAS concentrations in creeks across the island are presented in **Figure 2**. All concentrations from potential water sources across the island (other than Mission Creek) are significantly lower than those measured in the water used to water chickens from ID013. Given that the chicken egg results were marginally acceptable at ID013 (albeit with a level of uncertainty), the risks associated with watering chickens in catchments other than Mission Creek are assessed to be **low and acceptable**.

7.3.2 Screening assessment

Appendix H presents the derivation of conservatively defined screening levels for a pathway of egg consumption (where the eggs are from chickens exposed to PFAS via drinking water).

These screening levels are defined as the concentration in water which is estimated to result in the trigger points for chicken eggs provided in FSANZ, 2017. Trigger points are defined as the maximum concentration level of these chemicals that could be present in individual foods or food groups so where even at high consumption levels, consumers of these foods would not have dietary exposures exceeding the relevant health based guidance value. This means the screening levels below are highly conservative, as they are derived on the basis that 100% of an individual's fruit or vegetable intake comes from the source.

These screening levels are presented in **Table -2** below:

Table 7-2: Chicken drinking water screening levels

Produce type	Water screening level (µg/L)	
	PFOS	PFHxS
Egg	0.85	1.3

Concentrations in potential irrigation water sources across the island (other than Mission Creek) are compared with these screening levels in Table 6-3 (PFOS) and Table 6-4 (PFHxS) below:

Table 7-2: Comparison of PFOS concentrations measured in potential water sources outside Mission Creek to chicken drinking water screening levels

Creek	PFOS screening level (µg/L)	PFOS concentration (µg/L)		Number of samples
	Chicken eggs	Min	Max	
Watermill Creek	0.85	<0.01	0.29	13
Cascade Creek[28]		<0.01	0.1	9
Headstone Creek		<0.01	0.02	7
Rocky Point Creek		<0.01	<0.01	2
Other potential water sources (outside Mission Creek)		<0.01	0.01	19

Table 7-3: Comparison of PFHxS concentrations measured in potential water sources outside Mission Creek to chicken drinking water screening levels

Creek	PFHxS screening level (µg/L)	PFHxS concentration (µg/L)		Number of samples
	Chicken eggs	Min	Max	
Watermill Creek	1.3	<0.02	0.85	13
Cascade Creek[29]		<0.02	0.08	9
Headstone Creek		<0.01	0.02	7
Rocky Point Creek		<0.01	0.03	2
Other potential water sources (outside Mission Creek)		<0.01	0.04	19

PFAS concentrations in creeks across the island are presented in **Figure 2**. None of the measured concentrations exceeded the screening levels. The high level of conservatism in the screening level is emphasised. The screening level assumes high-end consumption rates, and also assumes that 100% of an individual's egg intake comes from chickens drinking this water. Given the conservatism in the screening level, and the absence of exceedances, the risks to consumers of chicken eggs from chickens watered with creek/bore water across the island are assessed to be **low and acceptable**

[28] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[29] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek

8.0 Risk assessment for firefighters

8.1 Issues identification

PFAS is present within water at the airport which has (until recently) been used for fire systems testing, training and firefighting, and (until recently) firefighters will have been exposed to this water through these uses.

Management of this use has been assessed to be warranted in order to limit the future introduction of PFAS into the environment (e.g. through testing of the fire systems which result in the release of water to ground). It is understood that management works are currently underway which will include the provision of treated water to underground tanks at the fire station. This will effectively manage future releases of PFAS-impacted water to the environment, and will also effectively prevent firefighter exposures to the PFAS in this water in the future.

Notwithstanding this and given that compliance testing of the management works is yet to be completed, the risks to firefighters associated with the measured concentrations of PFAS in water used for fire systems testing, training and firefighting (prior to management) have been further assessed here.

It is emphasised that the presence of PFAS in water recently used at the fire station is attributed to the historical use of fire-fighting foams (aqueous film-forming foams, referred to as AFFF) which contained PFAS. It is emphasised that the use of AFFF containing PFAS as an active ingredient during training at the airport has ceased, meaning the major historical source for PFAS to enter the environment has ceased. Works are underway to remove unused stocks of PFAS-containing AFFF from the island, and to clean the fire trucks in which PFAS-containing AFFF was historically used. The identified PFAS within water at the airport (to which firefighters were recently exposed) are related to residual impacts from historical (not current) use of AFFF containing PFAS.

8.2 Assessment approach

Threshold levels have been derived which offer protection to firefighters who are potentially exposed to water in the course of their duties (including fire systems testing, training and firefighting).

The measured concentrations in water used for fire operations (prior to the management measures described above) are compared with these threshold levels to assess potential risks.

8.3 Equations used in threshold level derivation

The equation used to estimate PFAS exposure via incidental ingestion is presented in Schedule B4 in the ASC NEPM (NEPC, 2013), and is adapted here for the water exposure scenario:

$$Intake\ (\mu g \cdot kg^{-1} day^{-1}) = \frac{C_w \cdot IR \cdot EF\ \cdot ED \cdot CF \cdot FI}{BW\ \cdot AT}$$

The exposure parameters referenced in this equation are described below.

Exposure parameter		Units
C_W	Concentration in water	µg/L
IR	Water ingestion rate	mL/event
EF	Exposure frequency	events/year
ED	Exposure duration	years
CF	Conversion factor	0.001 L/mL
FI	Fraction of ingested water from impacted source	-
BW	Body weight	kg
AT	Averaging time	days

To derive a Threshold Level, the equation is rearranged by setting the intake equal to the allowable daily intake, and solving for the corresponding allowable concentration in water (the Threshold Level, or TL):

$$TL\ (\mu g/L) = \frac{ADI \cdot BW \cdot AT}{IR \cdot EF \cdot ED \cdot CF \cdot FI}$$

8.4 Toxicity Assessment

The toxicity parameters adopted in this assessment are discussed in **Section 4.0**.

In line with the NEMP health investigation level (HIL) the threshold levels derived for firefighters allow for 80% of the allowable PFAS intake to be via other pathways (such as via drinking water and food) and only 20% of the allowable exposure to be via exposure pathways associated with exposure to water during fire systems testing, training and firefighting. This conservative approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water, or consumption of produce into which PFOS+PFHxS has bioaccumulated). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the HIL, exposures via this pathway contribute negligibly to risk.

8.5 Exposure Assessment

Exposure parameters have been defined as detailed below

Exposure parameter		Units	Adopted value	Notes
IR	Ingestion rate	mL/event	2	See discussion below
EF	Exposure frequency	events/year	Scenario 1: 52 Scenario 1: 240	See discussion below
ED	Exposure duration	years	30	Assumed time working as a firefighter. It is noted that the TLs are insensitive to the selected value, as the averaging time is set to be equal to the exposure duration for threshold contaminants such as PFAS, and the two parameters cancel out
CF	Conversion factor	L/mL	0.001	
FI	Fraction of ingested water from impacted source	-	1	It is conservatively assumed that all of the water to which personnel are exposed contains PFAS at the measured concentrations
BW	Body weight	kg	70	Adult body weight; adopted from the NEPM
AT	Averaging time	days	10,950	Set to be equal to the ED (30 days x 365 days/yr). It is emphasised that in the model the averaging time does not express the number of days that someone is exposed, instead it represents the total period over which exposure might occur. It is noted that the TLs are insensitive to the selected value, as the averaging time is set to be equal to the exposure duration for threshold contaminants such as PFAS, and the two parameters cancel out.

A key exposure parameter is the water ingestion rate (IR).

Incidental exposure due to spray drift associated with the discharge of water from trucks is the key potential ingestion pathway.

Reference has been made to the *Health Risk Assessment of Fire Fighting from Recycled Water Mains* prepared by the Water Services Associated of Australia (WSA, 2004) to estimate the likely ingestion rate during fire testing, training and firefighting. WSA (2004) determined the likely volume of water consumed during firefighting activities in consultation with firefighters from the NSW Fire Brigade. The potential exposure due to spray drift is generally 0.1–1 mL per fire-fighting event (with direct spray in the mouth equating to a volume of around 1 mL and swallowing spray drift equating to 0.1 mL). Allowance was also made for occasional accidental swallowing of larger volumes (up to 25 mL reported to occur for one in 50 fire fighters). WSA (2004) estimated that the median exposure during fire training events was 2 mL.

For the development of threshold levels, an ingestion rate of **2 mL/event** has been assumed. The adoption of the median exposure is considered appropriate for assessing potential risks to fire station personnel for whom potential exposure could occur over multiple events per year, for a period of up to 30 years.

As discussed in **Section 3.4** two scenarios have been assessed:

- Scenario 1: fire station personnel assumed to be exposed to water once a week (e.g. during systems testing when the exposure potential is greatest).
- Scenario 2: a more conservative scenario (considering potential exposure every working day from a variety of activities). This scenario is assessed to provide confidence that risks remain low even if exposure to water occurs every day.

In this context, adoption of the median ingestion rate is assessed to be appropriate and protective, as it is not plausible that high-end exposures (e.g. swallowing a mouthful of water) would occur on each occasion. This ingestion rate allows for both swallowing of spray drift, and direct spray in the mouth during each exposure event. It is noted that the adopted ingestion rate is likely to be highly conservative:

- **For those scenarios where direct exposure is likely to be of a limited duration**, such as training/testing events for which outlets may run, but unlikely for an extended period as could be the case for some larger-scale firefighting activities
- **Where PPE is worn**, such that the potential for ingestion of splashes/spray drift is reduced.

8.6 Threshold Levels

The derivation of thresholds for each of the assessed scenarios is presented in **Appendix I**. The results are summarised in **Table 4-3** below.

Table 8-1: Threshold levels for PFOS+PFHxS (µg/L)

Scenario		PFOS+PFHxS Threshold Level (µg/L)
Scenario 1	Exposure once a week	980
Scenario 2	Exposure every working day	210

8.7 Risk characterisation

As part of the DSI, water was sampled from the fire hydrants on the airport in January 2020 (FRE_TAP2). This water was used for fire systems testing, training and firefighting (prior to management). The measured concentration of PFOS+PFHxS in this water (15 µg/L) is compared to the threshold levels below:

Table 8-2: Comparison of measured PFOS+PFHxS concentrations to threshold levels (µg/L)

Scenario		Threshold Level (µg/L)	Measured concentration
Scenario 1	Exposure once a week	980	15
Scenario 2	Exposure every working day	210	

The concentration is more than 10 times below the threshold levels for both assessed scenarios:

- Scenario 1: where firefighters are exposed once a week, based on the likely frequency of fire testing activities when exposure potential is greatest; and
- Scenario 2: a conservative scenario assessed to provide confidence that risks remain low even if exposure to water occurs every day.

The risks associated with firefighters contacting this water for fire systems testing, training and firefighting (prior to management) is therefore assessed to be **low and acceptable**.

It is understood that management works are currently underway which will include the provision of treated water to underground tanks at the fire station. This will effectively manage future releases of PFAS-impacted water to the environment, and will also effectively prevent firefighter exposures to the PFAS in this water in the future.

9.0 Risk assessment for airport workers

9.1 Issues identification

The DSI assessed the risks to airport workers associated with incidental soil contact. It is noted that no surface water has been identified on the airport (i.e. drainage lines were found to be dry on multiple sampling visits, including after rain). Airport workers are therefore assessed to be incidentally exposed to soils only (and not water) during the course of their works.

In the DSI, concentrations in soil were assessed through comparison to the NEMP screening levels (HILs) which are conservative screening levels which offer protection to a range of people who might be exposed to PFAS in soil. There are different HILs for different land uses, including (for example) HILs for low-density residential use (HIL-A) and commercial industrial use (HIL-D). The risks from incidental soil contact by airport workers were assessed to be low and acceptable in the DSI. However, there are no NEMP screening levels developed specifically for intrusive workers (i.e. people who might work within soil excavations, such as utility maintenance workers, construction workers, or people engaged in earthworks). As there is a potential for increased soil exposure associated with these works, they have been further considered in the HHERA.

In addition, further consideration is also given to airport workers who work above-ground (i.e. not intrusive works), but spend the working day predominantly outdoors. This is to provide clarity that the HIL D scenario (which assumes someone working mainly indoors) is adequately protective for these workers.

9.2 Assessed pathways

The HHERA further considers the potential risks to intrusive workers who main come into contact with soil.

In the DSI, concentrations in soil were assessed through comparison to the NEMP screening levels (HILs) which are conservative screening levels which offer protection to a range of people who might be exposed to PFAS in soil. There are different HILs for different land uses, including (for example) HILs for low-density residential use (HIL-A) and commercial industrial use (HIL-D).

In the DSI, soil and sediment concentrations were compared to the HILs as follows:

- **On-airport and at the works depot:**
  - Soil concentrations on-airport were compared to the HIL-D for commercial industrial use, as this represents the closest exposure scenario for airport workers. Sediment concentrations were also compared to the HIL-D (a conservative approach which assumes contact with sediments in drains is equally likely as soil contact).
  - None of the concentrations in soil or sediment exceeded the HIL-D, indicating risks to workers are low and acceptable.
  - However, the HIL-D applies for general workers with limited access to soil is not directly applicable to in intrusive workers, given that intrusive workers will potentially have greater exposure to soil when compared with commercial workers (albeit exposure is unlikely to occur every working day). On this basis, the DSI recommended this pathway be further assessed in the HHERA to provide confidence that risks to intrusive workers are low and acceptable.

- **Off-airport (away from depot):**
  - In off airport areas away from the depot, concentrations in soil and sediment were compared to the HIL-A for sensitive low-density residential use. The HIL A is a conservative screening level which offers protection to sensitive users, and includes consideration of a pathway of growing home grown produce in the soil.
  - Only localised, marginal exceedances of the HIL-A were identified in soil. Some exceedances of the HIL-A were identified in sediment, but home-grown produce is unlikely to be grown significantly within creek bed sediments. Overall it was concluded in the DSI that the risk to sensitive users (including residents) from the measured concentrations in soil and sediment were low and acceptable.
  - The assessment for sensitive users completed for is considered to be highly conservative for intrusive workers, and risks to intrusive workers in off-site areas are therefore also assessed to be low and acceptable. Notwithstanding this, risks to intrusive workers in off-site areas are further assessed in the HHERA for completeness.

9.3 Approach

The following approach has been adopted for the risk assessment for intrusive workers:

- An adjusted human health investigation level (HIL) has been developed for intrusive workers, as described in **Section 9.2**.
- An adjusted human health investigation level (HIL) has been developed for outdoor airport workers, as described in **Section 9.2**.
- PFAS concentrations are compared to these HILs to assess risk (**Section 9.3**).

9.4 Intrusive worker HIL derivation

An HIL for PFOS + PFHxS protective of intrusive workers has been derived. This HIL is based on the HIL D for commercial/industrial workers presented in the PFAS NEMP. The derivation of the HIL values in the NEMP is described in the following document:

- State of NSW and Office of Environment and Heritage (NSWOEH), 2019: *Human health soil screening criteria for PFOS, PFHxS and PFOA: Calculation protocols and draft values for potential inclusion in the PFAS National Environmental Management Plan*

The approach followed here in the derivation of an HIL for intrusive workers is unchanged from the derivation approach for the HILs detailed in NSWOEH, 2019. All input parameters have been retained from the NSWOEH, 2019 derivation NEMP HIL D (for commercial/industrial use), with the exception of the following, which have been updated for the intrusive worker scenario:

- **Exposure frequency**: it is assumed that an individual intrusive worker (e.g. maintenance or construction worker) could be directly engaged in in-ground intrusive soil works for up to 20 days/year. This is considered to be a conservative estimate which allows for maintenance workers to be directly exposed to soils in trenches/excavations 1-2 days/month; it would also be protective for a worker on a construction project to be exposed daily within to soils within an excavation for an in-ground construction period of up to 4 working weeks. It is noted that the adopted value is more conservative than the assumed frequency for intrusive workers in CRC CARE (2011) (12 days/year).

- **Soil ingestion rate:** As a conservative measure, a soil ingestion rate of **330 mg/day** has been assumed for intrusive workers.
  - The adopted value is consistent with that adopted in the development of the HSLs for intrusive maintenance workers (CRC CARE, 2011).
  - The adopted ingestion rate is more than 10 times higher than the default value assumed for commercial/industrial workers (**25 mg/day**). This increased ingestion rate reflects the relatively high potential for soil exposure by intrusive workers engaging in in-ground works.
  - It is emphasised that the adoption of standard hygiene practices during the works will likely reduce the potential for soil exposure, and the adopted approach is therefore assessed to be conservative.
- **Dust inhalation parameters:** There are a range of exposure parameters which are used to assess the dust inhalation pathway. Each of these parameters have been conservatively updated to CRC CARE (2011) parameters for intrusive maintenance workers, which is a conservative approach which allows for more dust inhalation than the defaults for commercial workers. It is noted that changing these parameters has been undertaken to provide confidence in a conservative approach, but that altering these parameters has negligible impact on the overall HIL. This is because the dust inhalation pathway contributes negligibly (<<0.01%) to the overall risks posed to intrusive workers, which are instead driven by incidental soil ingestion. The amended parameters include:
  - **Time spent indoors/outdoors:** For commercial workers (in the NEMP HIL-D), it is assumed that 8 hours/day is spent indoors, and 1 hour outside. For intrusive workers, it is assumed that the full working day (8 hours) is spent outdoors. This is conservative, as dust concentrations are assessed to be higher outdoors.
  - **Particulate emission factor**: The particulate emission factor (or PEF) is used to estimate dust concentrations in outdoor air. The lower the PEF, the higher the dust concentration. For intrusive workers, a particulate emission factor of 4.4×10^8 m^3/kg is assumed (in line with CRC CARE 2011 for intrusive maintenance workers), which is around 100 times lower than the value assumed in the NEMP HIL-D (3.7×10^{10} m^3/kg).

It is noted that a pathway of dermal exposure is excluded from the NEMP HIL derivations presented in NSWOEH (2019), on the basis of the low potential for dermal uptake of PFAS, described in NSWOEH (2019) as follows:

> *"Dermal uptake was assumed to be negligible (ToxConsult 2016), therefore parameters relevant to this pathway were omitted from the equations. This approach is consistent with other chemicals in the HILs calculator for which dermal uptake is not significant."*

Dermal exposure pathways have therefore also been excluded for the intrusive worker HIL derivation.

The intrusive worker HIL derivation has been completed using the NEPM HIL spreadsheet; the derivation is presented in **Appendix J**. The HIL derived for the protection of intrusive workers is **15 mg/kg**.

9.5 Airport worker HIL derivation

An HIL for PFOS + PFHxS protective of outdoor airport workers has been derived. This HIL is based on the HIL D for commercial/industrial workers presented in the PFAS NEMP. This scenario conservatively considers an airport worker who could work full-time outdoors on the airport (i.e. 8 hours/day; 240 days/year), engaged in above-ground (non-intrusive works).

The assessed scenario is more conservative than the standard worker scenario, as it allows for the worker to be exposed to dust concentrations in air outdoors for longer periods, and has also conservatively assumed that the dust concentrations in air on the airport are higher than on a standard commercial site, as a result of various activities on the airport which might generate dust.

This scenario will offer a high level of protection to airport workers who work outside less frequently, and has been derived on a conservative basis to offer protection to all outdoor airport workers regardless of their working patterns.

The derivation of the HIL values in the NEMP is described in the following document:

- State of NSW and Office of Environment and Heritage (NSWOEH), 2019: *Human health soil screening criteria for PFOS, PFHxS and PFOA: Calculation protocols and draft values for potential inclusion in the PFAS National Environmental Management Plan*

The approach followed here in the derivation of an HIL for outdoor airport workers is unchanged from the derivation approach for the HILs detailed in NSWOEH, 2019. All input parameters have been retained from the NSWOEH, 2019 derivation NEMP HIL D (for commercial/industrial use), with the exception of the following, which have been updated for the intrusive worker scenario:

- **Dust inhalation parameters:** There are a range of exposure parameters which are used to assess the dust inhalation pathway. Each of these parameters have been conservatively updated to CRC CARE (2011) parameters for intrusive maintenance workers, which is a conservative approach which allows for more dust inhalation than the defaults for commercial workers. It is noted that changing these parameters has been undertaken to provide confidence in a conservative approach, but that altering these parameters has negligible impact on the overall HIL. This is because the dust inhalation pathway contributes negligibly (<<0.01%) to the overall risks posed to workers, which are instead driven by incidental soil ingestion. The amended parameters include:
  - **Time spent indoors/outdoors:** For commercial workers (in the NEMP HIL-D), it is assumed that 8 hours/day is spent indoors, and 1 hour outside. For airport workers, it is assumed that the full working day (8 hours) is spent outdoors. This is conservative, as dust concentrations are assessed to be higher outdoors.
  - **Particulate emission factor**: The particulate emission factor (or PEF) is used to estimate dust concentrations in outdoor air. The lower the PEF, the higher the dust concentration. For airport workers, a particulate emission factor of 4.4×10^8 m^3/kg is assumed (in line with CRC CARE 2011 for intrusive maintenance workers), which is around 100 times lower than the value assumed in the NEMP HIL-D (3.7×10^{10} m^3/kg).

It is noted that a pathway of dermal exposure is excluded from the NEMP HIL derivations presented in NSWOEH (2011), on the following basis of the low potential for dermal uptake of PFAS, described in NSWOEH (2011) as follows:

> *"Dermal uptake was assumed to be negligible (ToxConsult 2016), therefore parameters relevant to this pathway were omitted from the equations. This approach is consistent with other chemicals in the HILs calculator for which dermal uptake is not significant."*

Dermal exposure pathways have therefore also been excluded for the intrusive worker HIL derivation.

The airport worker HIL derivation has been completed using the NEPM HIL spreadsheet; the derivation is presented in **Appendix K**. The HIL derived for the protection of airport workers is **17 mg/kg**.

9.6 Risk characterisation: intrusive workers and airport workers

Reference should be made to the DSI for the full detail of the soil investigations completed both on-airport and off-airport. Table B2 and B3 of the DSI presents all of the soil and sediment concentrations respectively.

Maximum and 95%$UCL_{average}$[30] (95%UCL) concentrations are compared to the HILs developed to offer protection to intrusive workers (**15 mg/kg**) and airport workers (**17 mg/kg**) below:

Table 9-1: Comparison of PFOS+PFHxS concentrations (mg/kg) to intrusive worker and airport worker HILs

	Soil on-airport	Sediment on-airport	Soil at works depot	Other off-airport soil	Off-airport sediment
Maximum concentration	9.13	0.141	0.21	0.0171	0.524
95%UCL	0.361	0.0454	0.0707	0.00483	0.309
HIL for intrusive workers			15		
HIL for airport workers			17		

All concentrations (including maximum concentrations) are below the HILs, indicating:

- Risks to intrusive workers are **low and acceptable**
  - This scenario conservatively considers an intrusive worker who could be engaged up to 20 days/year on in-ground intrusive works.
- Risks to airport workers (working full time outdoors at the airport, but not engaged in intrusive works) are **low and acceptable**
  - This scenario conservatively considers an airport worker who could work full-time outdoors on the airport (i.e. 8 hours/day; 240 days/year), engaged in above-ground (non-intrusive works) but potentially exposed to elevated dust concentrations in air. This scenario will offer a high level of protection to airport workers who work outside less frequently, and has been derived on a conservative basis to offer protection to all outdoor airport workers regardless of their working patterns.

Because the maximum concentrations are below the HILs, this indicates that the risk to intrusive workers and airport workers is low and acceptable regardless of where they work on the airport. It is noted that the maximum concentrations will overestimate the overall concentrations to which workers could be exposed. The 95%UCLs in the table above indicate that the overall concentrations to which intrusive workers are likely be exposed are generally much lower than the maximum concentrations, and two or more orders of magnitude or more below the HIL.

Furthermore, it is noted that (in line with the NEMP HIL derivations) the HILs derived for intrusive workers and airport workers allow for 80% of the allowable PFAS intake to be via other pathways (such as via drinking water and food) and only 20% of the allowable exposure to be via soil contact pathways. This conservative approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water, or consumption of produce into which PFOS+PFHxS has bioaccumulated). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the HIL, exposures via this pathway contribute negligibly to risk.

On this basis, the overall potential exposures to intrusive workers and airport workers are assessed to be negligible, and further consideration of the contribution these pathways may make to cumulative exposures is not considered warranted.

[30] A key statistic is the 95% upper confidence limit on the mean (the 95%UCL); this concentration provides a 95% confidence level that the true population mean will be less than, or equal to this value. The 95%UCL for PFOS+PFHxS in soil and sediment in different domains (both on and off the airport) have been estimated in ProUCL, with the outputs provided in **Appendix L.**

10.0 Risk assessment for creek users

10.1 Issues identification

In the DSI, surface water concentrations in creeks were compared with the NEMP health based guidance value (HBGV) for recreational use in order to provide a preliminary screening assessment of the risks to creek users who might come into incidental contact with water in creeks. These users include workers (e.g. farmers) who might come into contact with creek water in the course of their work, and also people using the creek recreationally.

A number of the measured concentrations in Mission Creek exceeded the recreational screening level. On this basis, it was concluded in the DSI that further assessment of the potential risks associated with contacting the creek water in Mission Creek be undertaken in the HHERA.

None of the measured concentrations in other creeks on-island exceeded the recreational screening level. The risks from contacting the water in other creeks were therefore assessed to be low and acceptable and have not been assessed further in the HHERA.

10.2 Assessed pathways

The HHERA further assesses the risks associated with workers (e.g. farmers) or recreational users who may contact the water within Mission Creek.

There are a number of factors which influence the nature of exposure to the water in Mission Creek. Key factors include:

- **The ephemeral nature of Mission Creek:** Other than following times of increased rainfall, Mission Creek is often dry along much of its length, with water found only in small pools. This will limit the frequency of water contact, and also the degree of water contact which can occur (e.g. swimming or immersion for long periods is unlikely).
- **The limited access to the creek:** particularly in the upper reaches of Mission Creek the surrounding area is heavily vegetated which will restrict frequent or incidental access to the creek. This is described further in **Section 10.5**.

10.3 Approach

The NEMP recreational HBGV is likely to be highly conservative to assess risks to creek users who might come into incidental contact with water in creeks. The recreational criteria assumes frequent exposure (150 days/year) and conservative ingestion rates consistent with exposures during swimming:

- **Recreational contact:** Potential contact with surface water bodies for recreation purposes is considered to be low in Mission Creek, given the ephemeral nature of Mission Creek and limited access such that any recreational exposure is likely to be occasional. Surface water is unlikely to be used for swimming, and the potential for PFAS exposure will be much lower for other recreational uses when compared with swimming exposure.
- **Incidental contact by workers:** For workers (e.g. farmers) incidentally contacting this water, as the potential for exposure will be much less (both less frequent, and less extensive) than assumed in the derivation of the recreational criteria.

As such, the exceedances of the recreational criteria identified in the DSI do not indicate that elevated exposures are likely; merely that further assessment (taking into account likely exposures within the creek) should be undertaken in the HHERA.

The following approach has been adopted for the risk assessment for creek users:

- An adjusted screening level has been developed for creek users, as described in **Section 10.2.**
- PFAS concentrations are compared to this screening level to assess risk (**Section 9.1.2**).

10.4 Creek user screening level derivation

10.4.1 Derivation approach

A recreational HBGV of **2 µg/L** is incorporated into the PFAS NEMP 2.0. This HBGV was derived in the following document:

- NHMRC, 2019. *Guidance on Per and Polyfluoroalkyl substances (PFAS) in Recreational Water*

The HBGV incorporates a number of conservative assumptions:

- The HBGV assumes exposure occurs up to 150 times a year, and on each occasion, 200 mL of water would be drunk
- The HBGV for recreational use allows for 90% of the allowable PFAS intake to be via other pathways (such as via drinking water and food) and only 10% of the allowable exposure to be via water contact. This approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water, or consumption of produce into which PFOS+PFHxS has bioaccumulated). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the HIL, exposures via this pathway contribute negligibly to risk.

The approach followed here in the derivation of a screening level for creek users is unchanged from the derivation approach for the HBGV derived in NHMRC (2019) and incorporated into the NEMP 2.0. All input parameters have been retained from the NHMRC (2019), with the exception of the exposure frequency and ingestion rate, which have been updated to reflect possible exposures by users of Mission Creek. These updated exposure parameters are discussed below in Sections

10.4.2 Exposure frequency

It is assumed that an individual creek user could come into direct contact with creek waters up to 104 days/year (i.e. twice a week). This is considered highly conservative for all creek users, particularly given the limited access to the creek along much of its length, and the ephemeral nature of Mission Creek (i.e. water is not present year round at many locations).

10.4.3 Water ingestion rate

USEPA, 2019[31] presents incidental water ingestion rates measured for adults undertaking a variety of recreational activities. Many of the values presented are of limited relevance to likely exposures in Mission Creek (e.g. swimming, diving). However, some activities (e.g. fishing, wading, splashing) are likely to be more comparable to incidental exposures during farming/property maintenance works, or possible recreational use of the creek. Ingestion rates for the more relevant recreational activities are presented in **Table 10-1.**

[31] USEPA Exposure Factors Handbook Chapter 3 (Update): Ingestion of Water and Other Select Liquids.

Table 10-1: Incidental water ingestion rates for recreational activities (USEPA, 2019)

Ingestion rate (mL/hr)	Activity			
	Boating	Fishing	Wading/Splashing	Walking in water
Median	2.1	2.0	2.2	2.0
Mean	3.7	3.5	3.7	3.5
UCL[32]	11.2	10.8	11.2	10.6

Based on this range of ingestion rates, a water ingestion rate of **7 mL/event** has been adopted. This ingestion rate is considered conservative for the nature of exposures which could occur in Mission Creek, and allows for direct exposure to water for up to around two hours on each occasion where there is recreational or working access to the creek, assuming the mean ingestion rate would apply on each occasion:

- As discussed in **Section 10.2.2** exposure to water is assumed to occur twice a week. In this context of repeated exposure, consideration of the mean ingestion rates is likely to be most appropriate, as it is unlikely that high-end exposures (i.e. the UCL values in Table 10-1above) would occur repeatedly on each occasion.
- It is noted that the adopted ingestion rate would account for higher exposure on occasion, as it is the average exposure over longer timescales which determines risk. The adopted ingestion rate is also noted to allow for more than 30 mins direct exposure at the higher (UCL[34]) ingestion rates on each occasion.

The screening level derivation for creek users is presented in **Appendix M**. The screening level derived for the protection of creek users is **70 µg/L**.

10.5 Risk characterisation: creek users

The range in measured concentrations from surface waters collected in the Mission Creek catchment is compared below to the screening level for users of the creek.

Table 10-2: Comparison of measured Mission Creek concentrations to creek user screening level

Screening level for creek users	Measured PFOS+PFHxS concentrations in Mission Creek	
	Minimum	Maximum
70	0.17	67.2

All measured concentrations are below the screening level, indicating that the risks to creek users are **low and acceptable**.

The maximum concentration of PFOS+PFHxS (67.2 µg/L) is noted to be close to the screening level (70 µg/L). Even where concentrations are close to the screening level, there is considered to be a high level of confidence that risks will be low and acceptable, given the conservatism in the screening level.

[32] The UCL is the upper confidence limit; there is a 95% chance that the mean (average) exposure is below this value

Furthermore, it is noted that the maximum concentration is likely to overestimate the concentrations to which creek users would be exposed, for the following reasons:

- The maximum concentration was measured at the WWII Dam, located near the airport in the upper reaches of Mission Creek. There is very restricted access to this area given the nature of the terrain and the heavy vegetation, as depicted in **Figure 10-1** below, and the heavy vegetation at the Dam itself (**Figure 10-2**) further reduces the potential for the water to be entered. On this basis, the potential for exposure in this location is low.
- Concentrations of PFOS+PFHxS reduce along the course of Mission Creek. Excluding the WWII Dam, the next highest concentration was measured in SW21, located close to the WWII Dam, and also located in the upper reaches of Mission Creek where access is very restricted. Water access potential is also assessed to be very low in this location (as indicated in F**igure 10-3**)

Figure 10-1: The approach to the WWII Dam showing limited/difficult access to the area because of vegetation/terrain

Figure 10-2: The WWII Dam showing heavy surrounding vegetation and limited potential to enter the water

Figure 10-3: Mission Creek at SW21 showing heavy surrounding vegetation, difficult access and limited pooled water which will limit water exposure potential

- Away from the WWII Dam and SW21, all PFOS+PFHxS concentrations measured in surface water in Mission Creek are <10 µg/L (i.e. at least 7 times below the screening level), providing further confidence that away from these locations there are lower concentrations and lower PFAS exposure potential.
- The box and whisker plot[33] depicted in **Figure 10-4** below shows the total range of concentrations measured along the full length of Mission Creek (i.e. including the WWII Dam and SW21) compared with the screening level. It can be seen that all concentrations are below the screening level, and most of the concentrations are significantly below.

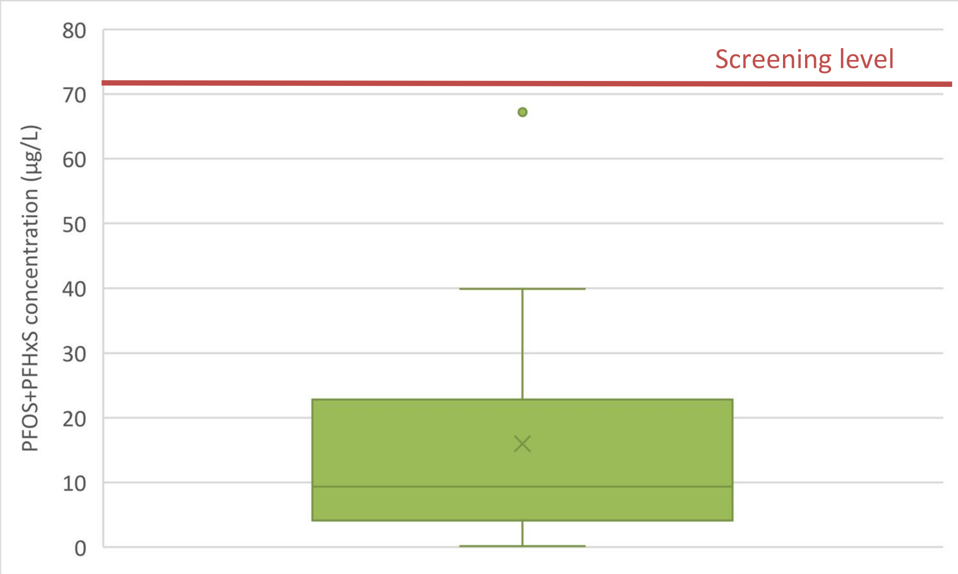


Figure 10-4: Box plot depicting range in concentrations of PFOS+PFHxS (µg/L) compared with the screening level for creek users (70 µg/L)

Overall, it is concluded that the risks to creek users associated with contacting the water in Mission Creek (for either work/farming purposes, or for recreation) are low and acceptable. All concentrations are below the screening level, and concentrations to which creek users are most likely to be exposed are at least seven times lower than the screening level.

Furthermore, the screening level is developed to be highly conservative to protect these users, incorporating conservative assumptions around the frequency and level of exposure which may occur. The screening level also allows for 90% of the allowable PFAS intake to be via other pathways (such as via drinking water and food) and only 10% of the allowable exposure to be via water contact pathways. This conservative approach is to allow for the potential for additional intake via other exposure pathways (e.g. via drinking water, or consumption of produce into which PFOS+PFHxS has bioaccumulated). This means that exceeding these values does not constitute a risk if other pathways are controlled; and conversely, where concentrations are below the screening level, exposures via this pathway contribute negligibly to risk.

On this basis, the overall potential exposures to creek users are assessed to be negligible, and further consideration of the contribution this pathway may make to cumulative exposures is not considered warranted.

[33] **How to read box and whisker plots:** A box and whisker plot shows the full range of the concentrations, together with a visualisation of where most of the concentrations sit. The body of the box and whisker plot (“the box”) represents the interquartile range (which is a measure of variability, based on dividing a data set into quartiles). 50% of sample results are within this range. The line in the middle of the box shows the median (middle) value, and the “×” shows the mean (average) value The boxes may have lines extending vertically called “whiskers”. These lines indicate variability outside the upper and lower quartiles, and any point outside those lines or whiskers is considered an outlier.

Further monitoring of Mission Creek should be undertaken as part of the PFAS Management Plan to better establish concentration trends, and the results should be compared to the screening level developed here (70 µg/L) to assess for any changes to the risk profile. If exceedances of the screening level are identified in the future, they should be considered in the context of the location and magnitude of the exceedances; the screening level is conservatively defined, and if there is low potential for access, exceedances are unlikely to indicate elevated exposure potential.

11.0 Summary outcomes of human health assessment

11.1 Pathways assessed to pose negligible risk

For the following pathways, risks are assessed to be negligible, and further assessment is not required:

- Home consumption or public consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment.
- Consumption of chicken eggs where chickens drink water sourced from outside Mission Creek catchment.
- Consumption of home produce (fruit/vegetables) grown within the Mission Creek catchment (at the one property where this currently occurs).
- Home consumption of public consumption of cattle products, where cattle are fed with grass cut from the airport.
- Consumption of home produce (fruit/vegetables) grown outside the Mission Creek catchment.
- Training and testing activities completed by firefighters using Airport Bore water.
- Incidental soil contact (both on-airport and off-airport) by intrusive workers.
- Water contact by creek users (workers and recreation) in all assessed creeks (including Mission Creek).

11.2 Pathways for which further assessment or management required

For the following pathways, further assessment and/or management is required:

- Home consumption or public consumption of cattle products where cattle drink water sourced from Mission Creek.
    - Risks to public consumers are assessed to be generally low and acceptable, with the exception of consumption of offal from one property, for which risks are likely to be low and acceptable, but cannot be entirely excluded. Nonetheless, there are a number of uncertainties in the assessment, and therefore further assessment and/or management is recommended.
    - It is emphasised that there are no regulatory restrictions with respect to PFAS in livestock products (including cattle products) and that, currently, there are no regulated maximum limits for PFAS in any foods in Australia or overseas[34] but research is ongoing.
- Consumption of chicken eggs where chickens drink water sourced from Mission Creek
    - Risks are low and acceptable based on the limited available data. Given the uncertainties associated with the limited data set, further assessment and/or management is recommended.

Further assessment and/or management should be completed as part of the PFAS Management Plan.

[34] SAFEMEAT, 2019. Issues brief: LPA and per- and polyfluoroalkyl substances (PFAS). Available from the Australian Government PFAS information portal (https://www.pfas.gov.au/audience/business)

11.3 Cumulative human health exposures

For all the assessed pathways, risks are either assessed to be negligible (see **Section 11.1**), or further assessment/management is required (see **Section 11.2**). Further consideration of potential cumulative risks associated with these pathways is not currently warranted, as discussed below:

- Where pathways are assessed to pose negligible risk (e.g. because concentrations are below conservative screening levels), it is concluded that exposures will not contribute significantly towards the overall risk profile, and further assessment of potential cumulative exposures across these pathways is not required.
- There are only a limited number of remaining pathways for which risks are assessed to be non-negligible. For each of these pathways, further assessment (to confirm the level of risk posed) and/or management (to reduce exposure potential) is required. In this context, further consideration of potential cumulative risks associated with these pathways is not currently warranted, as further assessment/management is required for these pathways even in the absence of considering the potential risks associated with exposure to multiple of these pathways.
- Required assessment/management actions should be documented as part of the PFAS Management Plan. This ongoing work should include provision to review the need for future cumulative assessment depending on the selected assessment/management options.

11.4 Temporal variability

This HHERA is based on the concentrations measured at the time of the PSI and DSI completed by Senversa. It is noted that there is insufficient data to fully establish trends in concentrations. Further monitoring is therefore required to assess how concentrations may change in the future. Changes in concentration could result in changes to the risk profile, and may require a review of the risk assessment presented here.

11.5 Future land uses or changed conditions

This HHERA is based considering the current land uses at the time of the PSI and DSI completed by Senversa. If land uses were to change in the future, it is noted that the risk profile may change. Specifically, the following are noted:

- **Within Mission Creek catchment:**
  - Further assessment or management is required for a pathway of consumption of products from beef cattle watered with water from Mission Creek (at several properties where this is known to occur). Other livestock have not been assessed as there is no indication they are currently present within the catchment. However, assessment or management would be required for other livestock if they were to be raised in Mission Creek catchment, or for beef cattle raised elsewhere in the catchment.
  - Further assessment or management is required for a pathway of consumption of eggs from chickens watered with water from Mission Creek (at a single property where this is identified to occur). If chickens were to be raised elsewhere in the catchment and watered with water from Mission Creek, assessment or management would be required.
  - Risks are assessed to be low and acceptable for consumption of produce (fruit and vegetables) irrigated with water from Mission Creek (at a single property where this is identified to occur). If produce were to be grown at other properties within the catchment, and irrigated with water from Mission Creek, assessment or management would be required as there are higher concentrations present elsewhere in the catchment.

- **Outside Mission Creek catchment:**
  - The assessment concludes low and acceptable risks via a broad range of pathways, including consumption of livestock products, chicken eggs, and produce (fruit and vegetables), and incidentally contact with soil and water.
  - All of the conclusions drawn are based on a broad consideration of concentrations identified (rather than considering specific exposures at specific properties). The conclusions are therefore assessed as likely to remain valid regardless of the precise land and water use at specific properties.

11.6 Continuation of management measures

There were a number of pathways for which the DSI assessed risks to be effectively managed through the use of existing management measures (e.g. advisory notices on water use, provision of alternate water supplies); these pathways have not been further assessed in the HHERA. The assessment of low risk via these pathways is therefore contingent on the continued use of management measures; continued management should be implemented through the PFAS Management Plan. A summary of management measures in place at the time of the DSI is provided in **Section 1.4.2**.

11.7 Data Gaps

The HHERA has identified a number of areas where risks are unlikely to be elevated, but additional data is required to confirm potential risks:

11.7.1 Grass concentrations in Mission Creek

While the risks to consumers of produce where the cattle have access to grass within Mission Creek are assessed to be low and acceptable, it is acknowledged that the available data regarding PFAS in grass within the Mission Creek bed is very limited, and that further sampling would therefore support the assessment.

As discussed in **Section 5.9** below, further assessment and/or management of the stock watering pathway for cattle which may access water within Mission Creek is assessed to be required. The requirement for further assessment/management of this pathway should be further assessed as part of the PFAS Management Plan.

11.7.2 Assessment of risk to consumers of pork products

There is limited literature data on which to estimate screening levels for pigs. On this basis, when coupled with the limited information regarding where pigs might be kept and stock watering sources for these animals, further assessment has not been undertaken at this stage. The following are noted:

- Water and Land use surveys have not provided any indication that pigs are kept in the Mission Creek catchment. This pathway is assessed as inactive.
- Risks from consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment are assessed to be low and acceptable (based on comparison to screening levels which assume high consumption rates). As noted in **Section 5.4.5**, the keeping of pigs is limited on island and consumption rates are likely to be generally lower than other livestock product types. On this basis, it is unlikely that elevated risks would be associated with the consumption of pork and other pig products where pigs drink water sourced from outside Mission Creek catchment. Notwithstanding this, risks cannot be fully excluded without additional information and/or assessment.

This is noted as a data gap; the requirement for further assessment/management of this pathway management of this pathway should be further assessed as part of the PFAS Management Plan.

12.0 Terrestrial ecological risk assessment

12.1 Problem identification

The terrestrial ecosystem is made up of all of the plants and animals that live on the land (as opposed to the aquatic ecosystem, which includes the plants and animals that live in the water.

Terrestrial ecological receptors can be exposed to PFAS impacts in soil as follows:

- **Direct exposure:** Species which live in the soil (e.g. soil microbes, invertebrates (insects and earthworms, and plants) can be directly exposed to PFAS
- **Indirect exposure:** PFAS can bioaccumulate within the species which live in the soil, and exposure can occur to other wildlife which consume these species as part of their diet, or to higher-order predators following bioaccumulation up the food chain. PFAS is taken up relatively readily by soil invertebrates (e.g. earthworms), so a key indirect exposure pathway is via the consumption of soil invertebrates as part of the diet of other species.

In the DSI, concentrations were compared with the ecological guideline values presented in the NEMP. A small number of the measured concentrations (both on-airport and off airport) exceeded the NEMP ecological guideline values. The DSI did note that the risks were likely to be low (based on the localised nature of the exceedances, and the generally low sensitivity of the areas where exceedances were identified), however it was recommended that pathways to terrestrial ecological receptors be considered further in the HHERA.

In addition to soil exposure, plants (e.g. deep rooted trees) can potentially be exposed to PFAS in groundwater. No screening level considering the risks to plant health associated with groundwater exposure is presented in the NEPM. This pathway has therefore also been assessed further in the HHERA.

12.2 Areas where further assessment is required

12.2.1 Rationale for selecting areas for assessment

The relevant areas for consideration in the terrestrial ecological assessment are those areas where PFAS impacts associated with the former use of AFFF have been identified in soil and/or sediment at concentrations above relevant screening levels. Consideration has been given to the identified exceedances of the ecological guideline values identified in the DSI to identify the areas for which potential receptors should be further considered.

12.2.2 On-airport

12.2.2.1 On-airport soil

The highest soil concentrations have been identified on-airport, with concentrations exceeding the ecological guideline values for both direct and indirect exposure. While the airport is generally considered a low sensitivity site, further assessment of the risks to terrestrial ecological receptors has been undertaken as part of this HHERA.

12.2.2.2 On-airport sediment

Sediments were collected from dry drainage features on airport. The measured concentrations were lower than those identified in soil. Given the dry nature of these drainage features, it is considered that exposure of terrestrial receptors on airport to these sediments will be similar to soil exposures. The sediment concentrations on airport will be considered together with the soil concentrations in the assessment.

The highest soil concentrations have been identified on-airport, with concentrations exceeding the ecological guideline values for both direct and indirect exposure. While the airport is generally considered a low sensitivity site, further assessment of the risks to terrestrial ecological receptors has been undertaken as part of this HHERA.

12.2.3 Off-airport

12.2.3.1 Off airport soil: works depot

The highest concentrations in soil (up to 0.155 mg/kg PFOS) were identified at the works depot, a commercial site which is paved and provides limited habitat. Given the nature of the works depot site, and the localised nature of the identified impacts, pathways of indirect exposure are assessed as likely to be inactive. The concentrations are below the conservative guideline value for direct exposure (1 mg/kg), and risks to terrestrial ecosystems are therefore assessed as likely to be low.

The NEMP indicates that where pathways of indirect exposure via the diet of terrestrial ecological receptors are likely to be inactive, an alternative criterion of 0.14 mg/kg may instead be considered. This criterion is considered to be of limited relevance, as it considers a pathway of leaching to groundwater and transport to surface water; there is a creek in the vicinity of the works depot, and the impact to this creek has been directly assessed via sediment sampling in the creek. Notwithstanding this, the maximum measured PFOS concentration at the works depot (0.155 mg/kg) is only marginally elevated above this alternate screening level. This exceedance is identified in sample DEPOT_SS01, located in the paved driveway, and closely delineated by other samples (SS02, SS03, SS15 and SS16) in which much lower concentrations of PFOS were identified (0.001 – 0.0464 mg/kg PFOS). These sampling results are depicted on **Figure 3**. The $95\%UCL_{average}$ for soils at the work depot is 0.0537 mg/kg[35]. On this basis, the overall concentrations at the works depot are below the alternative NEMP criteria applicable on sites of the nature. As such, risks are assessed to be low, and further assessment is not required.

12.2.3.2 Off airport soil: other locations

Away from the works depot, and the airport, only very low concentrations of PFOS in soil have been identified. No concentrations exceed the guideline value for direct exposure (1 mg/kg PFOS) and only one localised, marginal exceedance of the guideline value for indirect exposure was identified (0.0165 mg/kg in ID013_SS02, a private property where water from Mission Creek was previously used for irrigation.). This impact is localised in nature; a total of seven soil samples were collected from this property The other soil concentrations measured at this property were lower, ranging from 0.0014 – 0.0059 mg/kg PFOS. These sampling results are depicted on **Figure 4**. The $95\%UCL_{average}$[5] for soils on this property is 0.0097 mg/kg. Given the very localised and marginal nature of the impact, together with the fact that the overall concentrations on this property are below the conservative guideline value for indirect exposure (0.01 mg/kg PFOS), the risks on this property are assessed to be low and further assessment is not required.

[35] A key statistic is the 95% upper confidence limit on the mean (the 95%UCL); this concentration provides a 95% confidence level that the true population mean will be less than, or equal to this value. The 95%UCL for PFOS in off-site soils at the depot and at property ID013 have been estimated in ProUCL, with the outputs provided in **Appendix N**.

12.2.3.3 Off-airport sediment

Sediment concentrations are generally most relevant for the assessment of risks to the aquatic ecosystem. However, the creeks on island are ephemeral (i.e. sometimes or often dry), and when the creeks are dry, exposure of terrestrial receptors to these sediments may be similar to soil exposures. On this basis, the assessment of risks to terrestrial ecological receptors has also considered the sediment concentrations.

The range in sediment concentrations measured in different creeks is summarised in **Table 12-1.**

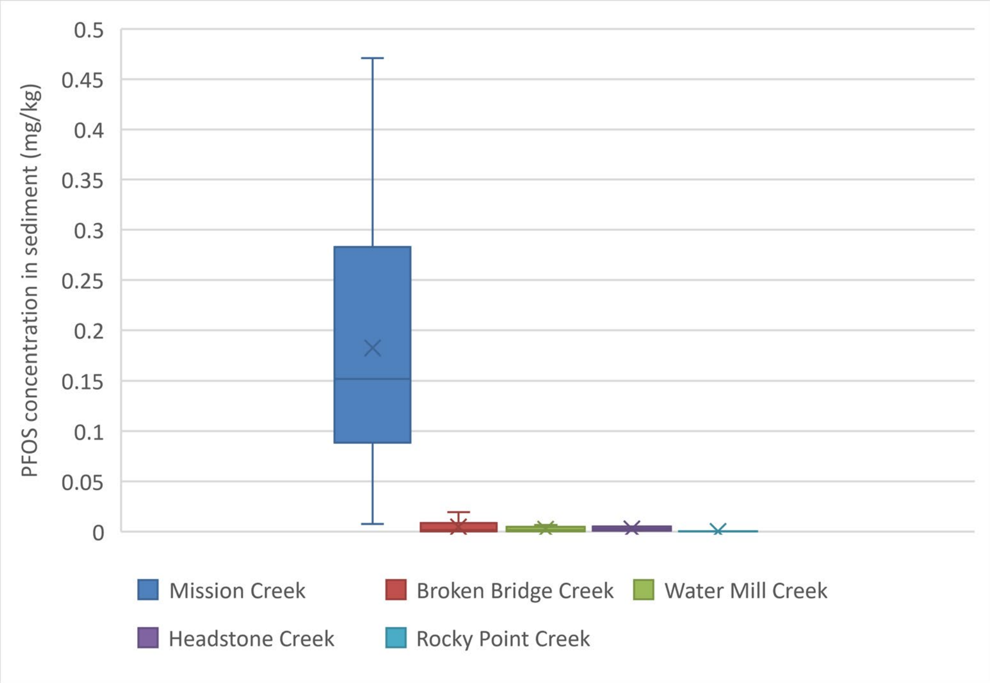
The box and whisker plot[36] depicted in Figure 12-1 below shows the total range of concentrations in each catchment.

Table 12-1: Ranges in sediment concentrations in different creek catchment zones

Catchment zone	Number of samples	PFOS concentration (mg/kg)		Exceedances of ecological guideline value for indirect exposure (0.01 mg/kg)?
		Min	Max	
Mission Creek	35	0.0075	0.471	Yes
Broken Bridge Creek[37]	14	<0.0002	0.0195	Yes
Water Mill Creek	11	<0.0002	0.0067	No
Headstone Creek	2	0.0008	0.0051	No
Rocky Point Creek	1	<0.0002		No

[36] **How to read box and whisker plots:** A box and whisker plot shows the full range of the concentrations, together with a visualisation of where most of the concentrations sit. The body of the box and whisker plot ("the box") represents the interquartile range (which is a measure of variability, based on dividing a data set into quartiles). 50% of sample results are within this range. The line in the middle of the box shows the median (middle) value, and the "×" shows the mean (average) value The boxes may have lines extending vertically called "whiskers". These lines indicate variability outside the upper and lower quartiles, and any point outside those lines or whiskers is considered an outlier.
[37] The Broken Bridge Creek catchment includes Cascade Creek, which is where the exceedances were identified

Figure 12-1: Box plot showing ranges in sediment concentrations in different creek systems



Exceedances of the conservative ecological guideline value for indirect exposure (0.01 mg/kg PFOS) were identified in only Mission Creek and Broken Bridge Creek catchments. The risks to ecological receptors in other catchments is therefore assessed to be low.

The highest sediment concentrations are measured in the sediments of Mission Creek. The maximum PFOS concentrations measured in Broken Bridge Creek catchment were more than 20 times lower than the maximum PFOS concentration measured in Mission Creek, and only marginally exceeded the conservative screening level (by less than a factor of two). As such, the key exposures requiring further assessment are those associated with Mission Creek. Notwithstanding this, further assessment of both Mission Creek and Broken Bridge Creek catchments has been undertaken for completeness.

12.3 Assessment approach

The assessment has been conducted in accordance with the NEPM framework for ecological risk assessment (ERA), described in **Section 2.2.** The following approach has been followed for this assessment:

- **Receptor identification (Section 12.3):** Potential receptors are described considering the species present across the broader island, and then reviewing which of these species may be present in the areas (both on-airport and off-airport) where PFAS impacts are present, and could be plausibly exposed to PFAS (via either direct or indirect exposure pathways). The overall sensitivity and environmental values of these areas is also described to provide context regarding the level of protection which is appropriate.
- **Toxicity assessment (Section 12.4):** Screening levels which offer protection to the potential receptors are defined.
- **Exposure assessment: (Section 12.4):** Exposure pathways to different receptors are discussed, including discussion of factors which will limit exposure (e.g. localised impacts and limited habitat/food sources)
- **Risk characterisation:** PFAS concentrations are compared with the adopted screening levels in order to assess the level of risk to terrestrial ecological receptors.

12.4 Receptor identification

12.4.1 Threatened species

Review of the EPBC Act Protected Matters Report extracted in May 2021 (**Appendix E** of the DSI) finds no threatened ecological communities listed, however 88 threatened on-island species and 44 migratory species that are known to occur in the area. The identified threatened species and their distribution are discussed further in **Section 12.4.2**

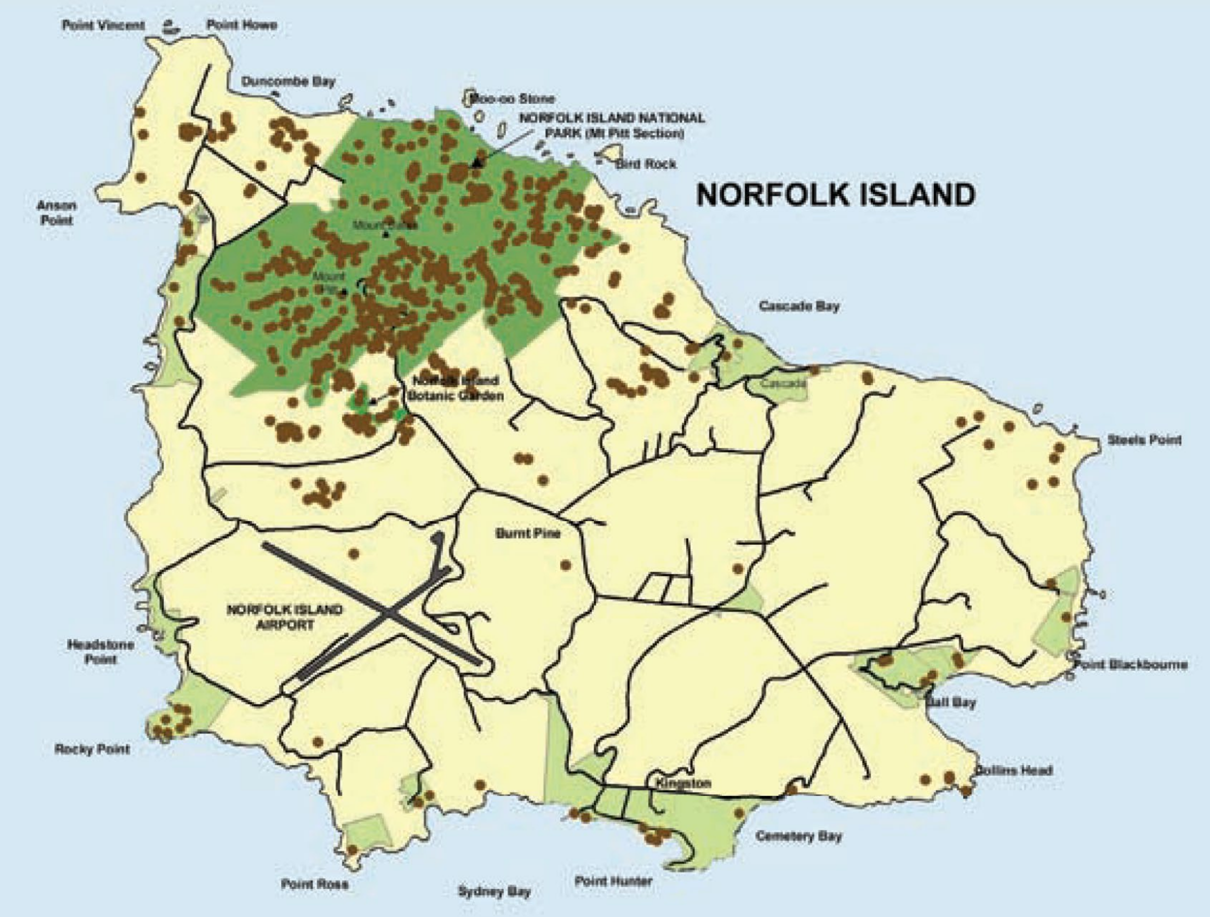
12.4.2 A summary of species identified on Norfolk Island

The *Norfolk Island Threatened Species Recovery Plan* (Director of National Parks (DNP), 2010) provides a description of the ecology of Norfolk Island, with a focus on detailing the threatened or protected species present on the island, and the locations where these maybe present. The following summary of the terrestrial ecological receptors on Norfolk Island has been developed based on review of DNP (2010) together with other literature sources as referenced below.

12.4.2.1 Plants

In 1788 the vegetation on the island comprised dense subtropical rainforest with Norfolk Island pine (*Araucaria heterophylla*) particularly abundant on the lower levels and slopes. The largest remnant of native forest today occurs in the national park, on the peaks of Mt Pitt and Mt Bates. A number of remnants occur sporadically in lower areas, where other native flora persists and where areas have been fenced from wandering cattle. The list of endemic flora species provided in DNP (2010) is provided in **Appendix O.** This list includes, but is not limited to, threatened species. The locations of threatened plant species are depicted by the dots on **Figure 12-1** below:

Figure 12-2: Distribution of threatened plant species (from DNP, 2010)



12.4.2.2 Birds

The fauna of Norfolk Island is notable for its endemic land birds and large numbers of seabirds. More than 100 species of birds have been recorded on Norfolk Island and adjacent islands in modern times. Of these, 32 species are resident breeding land or freshwater birds, 14 are regular breeding seabirds and six have become extinct since European settlement. The remainder are nonbreeding migrants or vagrants. **Appendix P** provides a list of bird species identified on Norfolk Island (both endemic and introduced species). The list is developed by Parks Australia and includes details on the habitats on-island in which they are found.

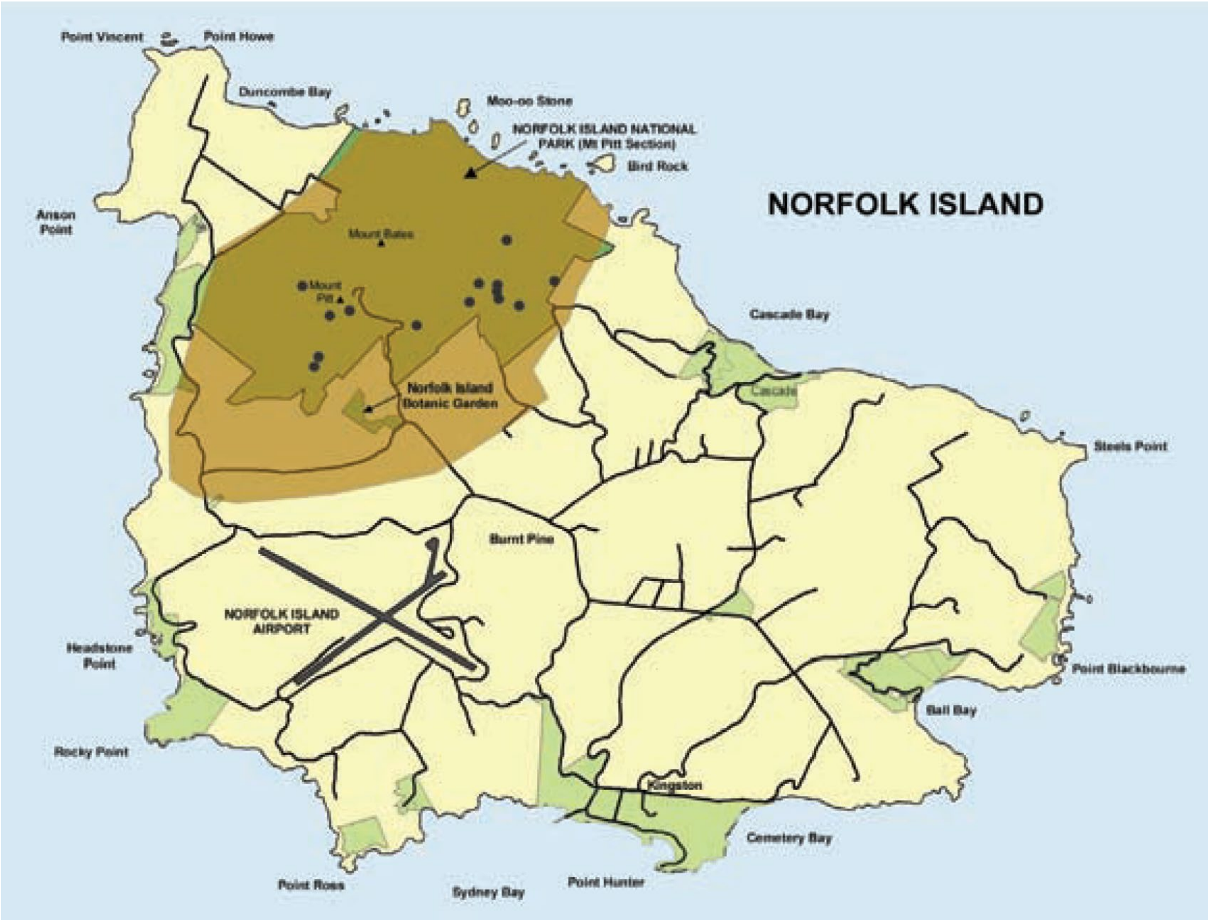
DNP (2010) provides details of two species of bird listed as endangered, and three species listed as vulnerable:

- **Endangered:** Norfolk Island Green Parrot (*Cyanoramphus cookii*) and Norfolk Island Boobook (*Ninox novaeseelandiae undulata*).
- **Vulnerable:** Golder Whistler (*Pachycephala pectoralis xanthoprocta*), Norfolk Island scarlet robin (*Petroica multicolor multicolor*), Kermadec petrel (western) (*Pterodroma neglecta*).

Of these, the Kermadec petrel is not found on the main island (only on Philip Island). The distribution of the other threatened species is depicted on **Figure 12-2** below:

- The shaded area centering on the Mt Pitt area of Norfolk Island indicates the approximate current range of the Golder Whistler (*Pachycephala pectoralis xanthoprocta*) and the Norfolk Island scarlet robin (*Petroica multicolor multicolor*). These vulnerable species are both forest dependent birds, and restricted to this area, focused on the National Park which contains the most significant remnant forest.
- The breeding sites of the Norfolk Island Green Parrot (*Cyanoramphus cookii*) and Norfolk Island Boobook (*Ninox novaeseelandiae undulata*) are located within the shaded area however their range extends across Norfolk Island.

Figure 12-3: Distribution of threatened bird species (from DNP, 2010)



12.4.2.3 Reptiles

There are two native land reptiles, the Lord Howe Island skink (*Oligosoma lichenigera*) and the Lord Howe Island gecko (*Christinus guentheri*) that are endemic to the Norfolk and Lord Howe Island groups. Neither is now found on the main island.

12.4.2.4 Mammals

The only native land mammals that have been recorded on Norfolk Island are the Eastern free-tail bat (*Mormopterus norfolkensis*) and Gould's wattled bat (*Chalinolobus gouldii*). According to DNP (2010), only the latter was seen in recent years. Both species are now extinct[38]. As in many other island ecosystems, introduced mammals have been responsible for significant environmental degradation. Introduced species include the Polynesian rat (*Rattus exulans*), the black rat (*Rattus rattus*), the house mouse (*Mus musculus*) and the feral cat (*Felis catus*).

[38] Parks Australia website, accessed September 2021. https://parksaustralia.gov.au/norfolk/discover/wildlife/

12.4.2.5 Invertebrates

Many species of invertebrates have been recorded on Norfolk Island Group, although there has never been a complete systematic survey. Identified species include:

- **Land snails:** There are 68 terrestrial species and one freshwater species, and almost all are endemic. 20 species appear on the 2008 IUCN Red List (IUCN 2008), of which six species are presumed extinct (including the only recorded freshwater mollusc), four species are considered endangered, eight species are considered vulnerable and two species are data deficient. Five species, *Advena campbellii*, *Mathewsoconcha suteri*, *Mathewsoconcha phillipii*, *Mathewsoconcha grayi* and *Quintalia stoddartii* are listed as critically endangered. Fossil records show most species were once widespread across the island, however they are now found primarily in the National Park and steep creek gullies in the remnants of the subtropical rainforest that once covered the island.
- **Grasshoppers and Crickets:** A survey in 1984 identified 21 species on Norfolk Island.
- **Butterflies and Moths:** There are 263 species that have been recorded on Norfolk and Phillip Islands.
- **Beetles:** There have been 304 species in 46 families identified of which 65 species were considered to be endemic.
- **Bees and wasps:** There are 219 species recorded from Norfolk Island or Phillip Island including nine endemic species. Many species are associated with low flowering herbs and annuals that are abundant in some parts of Phillip Island but excluded by introduced grasses on Norfolk Island; this introduced flora is generally unattractive to bees and wasps.
- **Ants:** Fifteen species of ants are known from Norfolk Island including one endemic species. The invasive Argentine ant (*Linepithema humile*) is a major threat to biodiversity because it can readily out-compete and displace native invertebrates, even to the point of local extinction. The worker ants can also interfere with nesting seabirds resulting in nest failure. CSIRO has therefore been working with Norfolk Island Regional Council (NIRC) since 2014 on an eradication project[39]
- **Centipedes:** One endemic centipede (*Cormocephalus coynei*) has been identified; it is restricted to Phillip and Nepean Islands.

12.4.3 Potential receptors: on-airport

Given the nature of the airport site, the potential for sensitive ecosystems to be present is likely to be low. Limited flora and fauna are present due to the highly modified nature of the airport environment, and the terrestrial environmental values of the airport are considered to be limited.

As the site is an airport, birds are excluded where possible, and any unpaved areas of the site is generally covered in grass. The main exception to this is the large Banyan tree present south west of the main terminal; the northern edge of the tree is shown together with a typical grassed area on **Figure 12-5** below.

[39] https://www.csiro.au/en/research/animals/pests/argentine-ant

Figure 12-4: Typical low-quality airport habitat (mown grass) with Banyan tree in background

The terrestrial receptors present will be largely limited to the soil microbes and invertebrates (e.g. earthworms) which live in the soil, and the site flora (mainly grass, and some trees).

Insects may be present, but flying insects visiting the site have a relatively low potential for exposure to PFAS given their low exposure to soil, and their limited potential for exposure via diet (given the limited food sources on site).

The only native mammals (bats) are extinct. The presence of feral mammals (e.g. rats, mice and cats) cannot be excluded, although it is noted that the nature of the airport site means there will be limited habitat or food sources to encourage presence at the site, and as feral pests, these are not assessed as species requiring protection.

The potential for birds to visit the site will be limited, but cannot be entirely excluded, although the potential for PFAS exposure for birds visiting the airport is likely to be low, given the poor habitat, and the low potential for birds to source a significant proportion of their diet from the airport.

Appendix O presents information regarding the species of birds present on Norfolk Island, and their habitats. The birds identified in “open areas” and “all habitats” are considered most likely to be visit the airport. These are mainly introduced species, but include 3 native and endemic species. None of the birds identified in “open areas” and “all habitats” are threatened.

Of the threatened birds identified on Norfolk Island, only two have ranges which overlap with the airport (the Norfolk Island Green Parrot (*Cyanoramphus cookii*) and Norfolk Island Boobook (*Ninox novaeseelandiae undulata*). These are both forest birds and are considered unlikely to visit the airport.

Table 12-1 lists the birds identified as most likely to visit the airport; the diet of these birds is detailed in the table. As previously noted, the birds with the highest potential for exposure to PFAS include birds which consume soil invertebrates as part of their diet; these include the European blackbird, the Song thrush, and the Feral Chicken (all introduced species).

Table 12-2: Bird species identified as most likely to visit the airport

Common name	Scientific name	Local name	Native range	Diet
Grey gerygone	Gerygone modesta	Hummingbird	Endemic	Insects
Sacred kingfisher	Halcyon sancta	Nuffka	Endemic	Mainly insects
Welcome swallow	Hirundo neoxena		Native	Insectivorous
European goldfinch			Introduced	Seeds and insects
European greenfinch			Introduced	Seeds and berries
House sparrow			Introduced	Mainly seeds, some insects
Common starling			Introduced	Insects
European blackbird			Introduced	Insects, earthworms, seeds and berries
Song thrush			Introduced	Earthworms, snails, fruit, berries
Feral pigeon			Introduced	Omnivorous, mainly fruits and grains
Feral chicken		Fowl / chook	Introduced	Omnivorous (fruits, seeds, insects, earthworms)
California quail			Introduced	Insects, plants
Crimson rosella		Red Parrot	Introduced	Omnivorous (fruits, seeds, insects)

In summary, the airport is assessed as low sensitivity habitat. Key terrestrial receptors groups identified on-airport include:

- Soil microbes and invertebrates (e.g. earthworms) which live in the soil;
- Plants (mainly grass, and some trees);
- Birds (the potential for birds to visit the site will be limited; however of the birds most likely to visit the site, the European blackbird, the Song thrush, and the Feral Chicken (all introduced species) are assessed to have the greatest potential for exposure to PFAS). Both herbivorous birds and omnivorous birds are assessed to be potentially present.

12.4.4 Potential receptors: off-airport

As discussed in Section **12.2.3**, the relevant off-airport areas for consideration in the terrestrial ecological assessment are limited to sediments in Mission Creek (along its length) and Cascade Creek (one localised, marginal exceedance only).

The upper reaches of Mission Creek (where the highest concentrations in sediment have been identified) are located within heavily vegetated remnant native forest.

Figure 12-5 below depicts the remnant rainforest habitat in the upper reaches of Mission Creek. Given the nature of this forest habitat, a wide range of potential species will be potentially present. It is, however, a relatively small area and is not listed as a National Park or other protected area of ecological significance. Field observations from during the DSI sampling program indicate that guava many invasive species are present throughout the habitat indicating its degraded quality compared with other remnant forest habitat on-island. Furthermore, DNP (2010) lists 21 sites of significant habitat on Norfolk Island outside the national park, including both significant and small forest remnants. The upper reaches of Mission Creek are not included on this list; this exclusion may relate to the presence of invasive species and its relatively small size of the area, further indicating the relatively low ecological significance of this area.

Figure 12-5: Example remnant rainforest habitat in the upper reaches of Mission Creek

Figure 12-6 below depicts one record of a threatened plant species being present in the upper reaches of Mission Creek where sediment impacts have been identified:

Figure 12-6: Location of threatened plant species in upper Mission Creek (adapted from DNP, 2010)

The lower reaches of Mission Creek are generally cleared and utilised for agriculture, and assessed to provide lower value ecological habitat than in the upper reaches. A typical example of the cleared, agricultural habitat in the lower reaches of Mission Creek (at a time when the creek was dry) is depicted in Figure 12-7: Example cleared habitat in the lower reaches of Mission Creek below:

Figure 12-7: Example cleared habitat in the lower reaches of Mission Creek

Cascade Creek in the vicinity of the identified marginal sediment impact is heavily vegetated, as depicted on **Figure 12-8** below. This area is likely to provided habitat to a range of species, though it represents less dense vegetation than the remnant rainforest identified in the upper reaches of Mission Creek.

Figure 12-8: Habitat in Cascade Creek, near the identified sediment impact

Overall, the key area for consideration in the assessment is the upper reaches of Mission Creek, as this is considered to be the most sensitive habitat in which PFAS has been identified in sediments at concentrations exceeding ecological guideline values. This is also the location in which the highest sediment concentrations have been identified. However, for the purposes of determining the full range of receptors which may be exposed to the identified impacts, all three areas discussed above have been considered together to provide confidence that all potentially relevant receptor groups are considered.

Based on the range of habitats identified, it is assessed that a broad range of the species identified on island (as discussed in **Section 12.4.2**) could be potentially exposed, including the following:

- **Soil microbes and invertebrates**
  - Threatened invertebrates on-island include endemic land snails. However, these are identified as unlikely to be present given their restriction largely to the National Park and steep creek gullies in the remnants of the subtropical rainforest. While a small portion of remnant rainforest is present in the upper reaches of Mission Creek, the areas is small, and this portion of forest is degraded in nature and colonised by invasive plant species. Notwithstanding this, the presence of land snails in this area cannot be entirely excluded.
- **Plants**
  - **Appendix O** details the range of endemic flora species identified on-island.
  - A wide range of plant species, potentially including threatened species could be potentially present in the relevant areas.

- **Birds**
  - **Appendix P** details the bird species identified on-island. With the exception of two vulnerable species (Golder Whistler and Norfolk Island scarlet robin) which are known to be restricted to the national park, all "forest birds" detailed in this appendix are considered potentially relevant.
  - Two endangered birds (the Norfolk Island Green Parrot and Norfolk Island Boobook) are assessed to be potentially exposed, although this assessment is considered conservative. Both birds have breeding ranges restricted to the national park, but may range across the island to forage/hunt. The Norfolk Island Green Parrot is described in Waldman (2016)[40] as leaving the National Park only occasionally to forage on orchard trees (not identified as present with the impacted creek areas); particularly for this species, the potential for exposure is assessed to be low.
  - Seabirds and waterbirds are not included in this terrestrial assessment. Seabirds are assessed as unlikely to be exposed to the impacts, given their generally coastal habitat and marine diet. Waterbirds which feed from dams and creeks are potential receptors for the aquatic ecological assessment (presented in **Section 13.0** of this report).
  - The birds assessed to be potentially exposed include:
    - Herbivorous birds (conservatively including the endangered Norfolk Island Green Parrot).
    - Omnivorous birds;
    - Carnivorous birds (two raptor species):
      - Norfolk Island Boobook owl (*Ninox novaeseelandiae undulata*; endangered); and,

Australian kestrel (*Falco cenchroides*; not listed).The only receptor groups which are excluded from the assessment are:

- **Reptiles:** no native reptiles are present on the island
- **Mammals:** the only native mammals (bats) are extinct. The presence of feral mammals (e.g. rats, mice and cats) cannot be excluded; and as feral pests, these are not assessed as species requiring protection.

12.4.5 Site sensitivity and adopted species protection level

For ecological direct contact pathways, the adopted ecological screening levels have been derived in accordance with the standard NEPM approach, by estimating the concentrations which will offer protection to a particular percentage of species (the species protection level), as described in **Section 12.4.1.** The appropriate species protection level is dependent on the environmental values associated with the site; a high species protection level applies on intact sites of great ecological importance, while lower species protection levels apply on disturbed sites, with the appropriate species protection level varying with land use. It is noted that the species protection level is only relevant for the assessment of direct exposure pathways; for indirect exposure pathways (i.e. exposure via the diet, following bioaccumulation of PFAS up the food chain) a different methodology is adopted, which considers risks to individual species representative of different receptor groups.

Consideration has been therefore given to the range of land uses for which species protection levels have been defined in the NEPM in order to select the species protection level most appropriate for the site setting and sensitivity.

The NEPM land uses and species protection levels are defined in Table 12-3 below.

[40] Waldman, 2016. *Foraging Ecology of the World's Only Population of the Critically Endangered Tasman Parakeet (Cyanoramphus cookii), On Norfolk Island* (Masters thesis)

Table 12-3: Percentage of Species and Soil Processes to be Protected for Different Land Uses (as per NEPM Schedule B5b)

Land use	Standard % protection	Biomagnification[a] % protection
Urban residential	80	85[b]
Public open space	80	85[b]
Commercial	60	65[c]
Industrial	60	65[c]
Agricultural	95[d] and 80[e]	98[c,d] and 85[c,e]
Areas of ecological significance	99	99

[a] if a contaminant meets the criteria for biomagnification, [b] if surface area exceeds 250 m^2, [c] if surface area exceeds 1,000 m^2, [d] agricultural crops, [e] for soil processes and terrestrial fauna.

The following species protection levels have been adopted:

- **On-airport:** as a conservative measure, a species protection level of 85% has been selected; this species protection level is relevant for bioaccumulative contaminants (such as PFAS) on open space areas. It is noted that in highly modified areas of the site (e.g. with hardstand and infrastructure present), the species protection level for commercial land use (65%) may be more relevant.
- **Off-airport:** a species protection level of 85% has also been adopted as the most relevant species protection level for off-site areas.
  - This species protection level is considered relevant for vegetated areas outside of protected areas (such as national parks) and is also the relevant species protection level for the protection of ecological receptors (not crops) on agricultural land
  - The NEPM indicates that an area of ecological significance is one where the planning provisions or land use designation is for the primary intention of conserving and protecting the natural environment. This would include national parks, state parks, wilderness areas and designated conservation areas. As no such designation applies to the remnant rainforest in the upper reaches of Mission Creek, this species protection level is not considered applicable. This is supported by the noted presence of invasive species through the area. However, noting the potential presence of threatened plant species in the upper reaches of Mission Creek consideration has also been given to the 99% species protection level to provide additional confidence in the risk assessment.

12.5 Toxicity assessment

12.5.1 Approach

Within this toxicity assessment, the basis of the conservative ecological guideline values utilised in the DSI has been reviewed in order to assess their relevance to the receptors identified in **Section 12.4**. Where warranted, alternate screening levels more relevant for the protection of the identified receptors have been selected or derived.

It is noted that no screening levels were identified in the DSI to assess the exposure of plants (e.g. deep-rooted trees) to groundwater. A literature review has been undertaken to identify screening levels for groundwater protective of plant health.

The refined screening levels presented in this section are then compared to the measured PFAS concentrations to assess risks. This comparison is undertaken in **Section 12.7** (soils and sediments on-airport) **Section 12.8** (sediments off-airport) and

12.5.2 Screening Levels for Ecological Direct Contact

The screening level for ecological direct contact pathway considers the risk associated with direct exposures to plants, invertebrates and soil microorganisms.

The PFAS NEMP and the PFAS NEMP 2.0 both include a screening level of 1 mg/kg for ecological direct exposure. This screening level is recommended for interim use as a screening level for direct ecological contact by terrestrial ecological receptors in the NEMP "in the absence of acceptable published guidelines" However, it is derived for the protection of human health via incidental soil contact (open space land use), and as such does not provide a direct assessment of potential terrestrial ecological risks. On this basis, reference has been made to screening levels from other sources / jurisdictions which more directly considered the potential risks associated with the ecological direct contact pathway.

CRC CARE, 2018 *Practitioner guide to risk-based assessment, remediation and management of PFAS site contamination* presents ecological screening levels (ESL) for ecological direct contact derived using a species sensitivity distribution (SSD) approach generally consistent with the NEPM EIL derivation framework; screening levels are presented for different land uses with species protection levels defined in accordance with the NEPM.

- The CRC CARE ESL for urban residential / public open space (32 mg/kg PFOS) is defined based on an 85% species protection level, which is the species protection level considered appropriate for bioaccumulative COPC both on and off the airport (see **Section 12.4.5**).
- For the off-airport assessment consideration has also been conservatively been given to the CRC CARE ESL for areas of ecological significance (6.6 mg/kg PFOS) defined based on a 99% species protection level. As discussed in **Section 12.4.5**, this is a conservative approach.

Consideration has also been given to the Canadian Soil Quality Guidelines for ecological soil contact (sourced from Environment and Climate Change Canada (ECCC), 2017[41]. These guidelines are derived using a similar SSD methodology, but with some differences to the NEPM approach (around adopted species protection levels, and the approach used to select data for inclusion in the derivation). Reference to CCME has also been made as the derivation incorporates a number of studies not referenced by CRC CARE. The CCME ESL for residential / parklands (11 mg/kg PFOS) is defined based on an 75% species protection level, and is considered most relevant to this assessment, and has been adopted together with the CRC CARE values for comparison purposes.

12.5.3 Screening Levels for Ecological Indirect Contact (Bioaccumulation Pathways)

PFAS can bioaccumulate within the species which live in the soil, and exposure can occur to other wildlife (e.g. birds) which consume these species as part of their diet, or to higher-order predators following bioaccumulation up the food chain. The screening level for ecological indirect contact pathways considers the risk associated with these pathways.

For pathways of bioaccumulation through the ecological food web, PFOS screening levels are not based on a species protection level, but are instead derived through the modelling of uptake and consumption through the food chain in order to offer protection to an individual (representative) species.

The NEMP includes a screening level of 0.01 mg/kg PFOS for bioaccumulation pathways, sourced from Canadian guidance (ECCC, 2017[1]). ECCC presents screening levels for a range of receptor types derived in this manner, and the 0.01 mg/kg value presented in the NEMP is the most stringent value, derived to offer protection to the most sensitive receptor type (a small insectivorous mammal). As discussed in 12.4, the only native mammals (bats) are extinct. The presence of feral mammals (e.g. rats, mice and cats) cannot be excluded; and as feral pests, these are not assessed as species requiring protection.

[41] ECCC,2017. Federal Environmental Quality Guidelines: Perfluorooctane Sulfonate (PFOS)

On this basis, consideration has been given to the screening levels derived for other (non-mammalian) receptor types in ECCC, 2017, in order to select screening levels which offer appropriate protection to the receptor groups identified as likely to be present in both on-airport and off-airport areas (these species are summarised in **Section 12.4.3** (on-airport) and **Section 12.4.4** (off-airport). **Table 12-4** details the ECCC soil quality guidelines relevant to potential receptor groups both on and off-airport. These screening levels are assessed to be highly conservative, as they assume 100% of the diet is sourced from PFAS impacted areas, which is unlikely given the localised nature of the impacts, particularly in of-site areas.

Table 12-4: ECCC PFOS soil quality guidelines relevant to potential receptors on airport and off-airport

Receptor Group		Receptor group assessed as potentially present		Representative species used in ECCC derivation	ECCC soil quality guideline (mg/kg PFOS)
		On-airport	Off-airport		
Tertiary consumer	Carnivorous birds	×	✓	NA	NA
Secondary consumer	Omnivorous birds	✓	✓	American Robin	0.33
Primary Consumer	Herbivorous birds	✓	✓	Rock dove	5.1

Two carnivorous birds (raptors, or birds of prey) have been identified on-island and are assessed to be potentially present in off-site areas:

- Norfolk Island Boobook owl (*Ninox novaeseelandiae undulata*; endangered); and
- Australian kestrel (*Falco cenchroides*; not listed).

No relevant screening level for carnivorous birds is presented in ECCC, 2017. A site-specific screening level has been derived utilising the same approach as adopted in ECCC, 2017, but incorporating species-specific literature-sourced parameter values (e.g. body weight, food ingestion rate) for the species listed above.

The screening level is assessed to be highly conservative, as it assumes 100% of the diet is sourced from PFAS impacted areas, which is unlikely given the localised nature of the impacts off-site areas, which are restricted to localised impacts within creek sediments. The screening level also conservatively assumes a diet comprising 100% soil invertebrates (this taxonomic group has the greatest potential for PFAS uptake). The diet of these birds is instead likely to be composed of above-ground and flying invertebrates and small mammals (e.g. mice) into which the PFAS uptake potential is lower.

This derivation is presented in **Appendix Q**, and the resulting screening level derived to offer protection to carnivorous birds is **0.66 mg/kg PFOS**.

12.5.4 Groundwater Screening Levels protective of plant health

Environment and Climate Change Canada (ECCC) developed environmental quality guidelines for PFOS (ECCC, 2017[42]). The groundwater value to protect soil organisms (such as plants) from adverse effects via direct contact with groundwater was 2 mg/L PFOS.

Limited information is presented around the derivation of this guideline, and reference to this guideline is absent from recent ECCC publications, however there is evidence in the broader literature that the phytotoxicity of PFAS is relatively low, and that effects on plant health, where observed) occur at much higher concentrations than other ecological effects (e.g. associated with bioaccumulation through the food chain), and at higher concentrations than are generally observed in the environment:

- A review undertaken by Costello & Lee[43] considered PFAS sources and fate processes relevant to agricultural systems and reviewed plant uptake mechanisms and plant responses to PFAS. This review discusses the relatively low phytotoxicity of PFAS; effects on plant health are observed in some studies, but at high concentrations. For example, effects were observed in wheat but only at higher concentrations (100,000–200,000 µg/L). The review noted that stress responses were not observed at the field scale when irrigating fields or applying PFAS-containing fertilisers as the concentrations observed in the environment are generally lower than the concentrations at which phytotoxic effects occur. The low phytotoxicity of PFAS identified in the review supports the use of the ECCC screening level.
- A plant uptake study was undertaken for Defence (for RAAF Base Williamtown) as part of the Off-site Human Health Risk Assessment (AECOM, 2017, available online[44]). This study including the growing of a range of fruit and vegetable plants utilising PFAS impacted water. The highest dosing rate used in this study was 100 µg/L for each of the target PFAS (including PFOS + PFHxS); while some effects on plant health were observed in the study, these were attributed to other factors (e.g. infestation, salinity) and were not found to be dose related or attributable to PFAS. This study therefore provides an indication that effects on plant health would not be expected at groundwater concentrations <100 µg/L. The low phytotoxicity of PFAS identified in the review supports the use of the ECCC screening level.

On this basis, a screening level of 2 mg/L PFOS has been retained to assess the risks to plant health where plants are exposed to PFAS in groundwater (e.g. via the root system of deep-rooted trees).

12.6 Exposure assessment

Terrestrial ecological receptors can be exposed to PFAS impacts in soil as follows:

- **Direct exposure:** Species which live in the soil (e.g. soil microbes, invertebrates (insects and earthworms, and plants) can be directly exposed to PFAS.
- **Indirect exposure:** PFAS can bioaccumulate within the species which live in the soil, and exposure can occur to other wildlife which consume these species as part of their diet, or to higher-order predators following bioaccumulation up the food chain. PFAS is taken up relatively readily by soil invertebrates (e.g. earthworms), so a key indirect exposure pathway is via the consumption of soil invertebrates as part of the diet of other species.

Section 12.2 discusses the areas where PFAS impacts relevant to these exposure pathways are present in soil and/or sediment. The soil and sediment concentrations discussed in **Section 12.2** and considered relevant to this assessment include:

- All measured soil and sediment concentrations on the airport.
- Sediment concentrations in Mission Creek, and one location in Cascade Creek.

The assessment has conservatively considered soils from all depths for the purpose on initial screening, even though exposure to deeper soils by ecological receptors will be limited.

[42] ECCC, 2017. Federal Environmental Quality Guidelines: Perfluorooctane Sulfonate (PFOS)
[43] Costello & Lee, 2020. Sources, Fate, and Plant Uptake in Agricultural Systems of Per-and Polyfluoroalkyl Substances
[44] https://www.defence.gov.au/environment/pfas/williamtown/publications.asp

In addition, plants (e.g. deep rooted trees) can be exposed to PFAS in groundwater. Groundwater has been sampled from the airport bore, and also from a number of private bores. The highest concentrations were measured in groundwater sampled from the airport bore, located near the on-airport sources; the concentrations measured in the airport bore are considered likely to be representative of the highest groundwater concentrations which could be present on or close to the airport. For the purposes of initial screening, the potential risks to plant health associated with concentrations in the airport bore have been assessed; this assessment will be conservative for off-airport areas where lower concentrations have been measured, or would be expected.

12.7 Risk characterisation: on-airport

A soil concentrations are presented in Table B2 of the DSI. All sediment concentrations are presented in Table B3 of the DSI.

The maximum concentration of PFOS in on-airport areas (in either soil or sediment) is 9.09 mg/kg PFOS, measured soil sample A_SS109 in source area PS04. The 95%UCL[45] for PFOS in soils and sediments on airport is 0.316 mg/kg.

For initial screening purposes, the range of screening levels developed to protect ecological receptors have been compared to the maximum concentration and the 95%UCL. This comparison is presented in **Table 12-5** below.

Table 12-5: Comparison of PFOS concentrations on-airport to terrestrial ecological screening levels

PFOS exposure pathway	Source for screening level	PFOS screening level (mg/kg)	Is the max PFOS concentration (9.09 mg/kg) greater than the screening level?	Is the 95%UCL PFOS concentration (0.316 mg/kg) greater than the screening level.	Risk characterisation
Direct exposure to plants, invertebrates and soil microorganisms	CRC CARE 85% species protection level	32	No	No	Risks low and acceptable
	ECCC ESL for residential / parklands	11	No	No	Risks low and acceptable
Indirect exposure to herbivorous birds	ECCC soil quality guidelines	5.1	Yes	No	Further assessed below
Indirect exposure to omnivorous birds	ECCC soil quality guidelines	0.33	Yes	No	Further assessed below

[45] A key statistic is the 95% upper confidence limit on the mean (the 95%UCL); this concentration provides a 95% confidence level that the true population mean will be less than, or equal to this value. The 95%UCL for PFOS in soil and sediment on-airport have been estimated in ProUCL, with the output provided in **Appendix N**. It is noted that the 95%UCL is likely to overestimate the overall concentration across the airport, given the targeted source area sampling completed in the DSI.

The comparison indicates the following:

- **Plants, invertebrates and soil micro-organisms:**
  - None of the measured concentrations exceed the screening levels adopted for the protection of plants, invertebrates and soil micro-organisms via a pathway of direct exposure. The risks to these receptors are therefore assessed to be **low and acceptable**.
- **Birds:**
  - The maximum concentrations exceed the screening levels adopted for the protection of herbivorous birds and omnivorous birds via a pathway of indirect exposure (i.e. exposure to PFAS in the diet).
  - The 95%UCL concentration is below the screening levels for each of these receptor groups, indicating that for receptors exposed across the broader airport, exposure concentrations would be below acceptable levels.
  - As discussed in **Section 12.4.3**, the nature of the poor quality habitat on the airport is such that the potential for birds to visit the airport will be limited, and there is low potential for birds to source a significant proportion of their diet from the airport. It is noted that no threatened species are assessed as likely to visit the airport, and that the species assessed to have the greatest potential for exposure to PFAS (the European blackbird, the Song thrush, and the Feral Chicken) are all introduced (non-native) species.
  - The locations of the exceedances are depicted on **Figure 5**. This figure shows the localised nature of the identified exceedances. The majority of the exceedances, and the highest concentrations, are identified in the area of current drill ground, which is a heavily utilised works are with very limited vegetation. The localised nature of the exceedances, and their focus in areas where limited, if any, food sources would be present provide additional lines of evidence that birds visiting the airport would be unlikely to source a significant proportion of their diet from the areas where screening level exceedances have been identified.

Overall, the risk to birds visiting the airport is assessed to be low and acceptable.

12.8 Risk characterisation: off-airport

12.8.1 Initial screening of maximum concentrations

All sediment concentrations are presented in Table B3 within the DSI.

The maximum concentration of PFOS in off-airport areas is 0.471 mg/kg PFOS, measured in the sediments of Mission Creek at location MC_SD27. For initial screening purposes, to the range of screening levels developed to protect ecological receptors have been compared to this maximum concentration. Given the linear nature of the identified sediment impacts and their wide geographic distribution, it is not considered relevant to adopt a statistical approach for the sediment data to assess overall exposure concentrations, though it is emphasised that maximum concentrations will overestimate the overall concentrations to which receptors could be exposed.

Where no exceedances are identified, the risks are assessed to be low and acceptable. Where exceedances are present, this does not necessarily indicate unacceptable risks, instead, further assessment has been undertaken taking into consideration the extent of the identified exceedances, in order to qualitatively assess the potential for receptors to source a significant proportion of their diet from impacted areas.

Table 12-6: Comparison of the maximum PFOS concentration in off-site sediments (0.471 mg/kg) to screening levels for different terrestrial ecological exposure pathways

PFOS exposure pathway	Source for screening level	PFOS screening level (mg/kg)	Is the max PFOS concentration (0.471 mg/kg) greater than the screening level?	Risk characterisation
Direct exposure to plants, invertebrates and soil microorganisms	CRC CARE 85% species protection level	32	No	Risks low and acceptable
	CRC CARE 99% species protection level	6.6	No	Risks low and acceptable
	ECCC ESL for residential / parklands	11	No	Risks low and acceptable
Indirect exposure to herbivorous birds	ECCC soil quality guidelines	5.1	No	Risks low and acceptable
Indirect exposure to omnivorous birds	ECCC soil quality guidelines	0.33	Yes	Further assessed below
Indirect exposure to carnivorous birds	Site-specific value	0.66	No	Risks low and acceptable

The following conclusions are drawn:

- The maximum concentration of PFOS exceeds the screening level for the protection of **omnivorous birds**.
  - The risk to omnivorous bird species has been further assessed in **Section 12.8.2** taking into consideration the extent of the identified exceedances, in order to qualitatively assess the potential for receptors to source a significant proportion of their diet from impacted areas.
- The maximum concentration of PFOS does not exceed the screening levels developed for the protection of other potential receptors (including **plants, invertebrates, soil micro organisms, herbivorous birds or carnivorous birds**).
  - As such the risk to these receptor groups is assessed to be **low and acceptable**.
  - It is noted that the threatened species identified to be potentially present in the areas of PFAS-impacted sediments are limited to:
    - plant species;
    - endemic land snails (unlikely to be present, but presence not entirely excluded, as discussed in **Section 12.4.4**);
    - one herbivorous bird (Norfolk Island Green Parrot (*Cyanoramphus cookii*)); and one carnivorous bird (Norfolk Island Boobook (*Ninox novaeseelandiae undulata*)) (both of these birds also unlikely to be present as discussed in **Section 12.4.4)**.
  - The risks to these threatened species are therefore assessed to be **low and acceptable**.

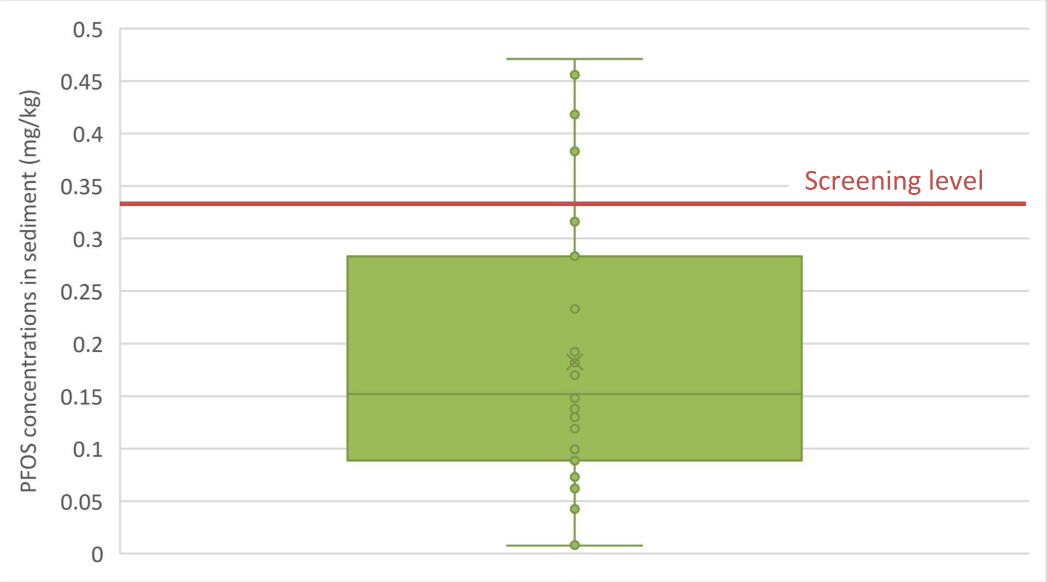
12.8.2 Further assessment of the risks to omnivorous birds

The exceedances of the screening level are restricted to samples within Mission Creek.

Outside of Mission Creek, the maximum sediment concentration is 0.0195 mg/kg PFOS, which is more than 10 times below the screening level to protect omnivorous birds. The risk to omnivorous birds outside of the Mission Creek catchment is therefore assessed to be **low and acceptable**.

Within Mission Creek, 6 of the 35 samples collected along the creek exceeded the conservatively defined screening level developed to protect omnivorous birds. These exceedances are relatively marginal in nature (i.e. <50% higher than the screening level). The box plot[46] below depicts the range of concentrations measured within Mission Creek, shows that the majority of concentrations are below the screening level:

Figure 12-9: Box plot showing the range in sediment concentrations in Mission Creek compared with the screening level for omnivorous birds



The identified exceedances of the screening level are depicted on **Figure 6**. It can be seen from the distribution of these impacts that the area of impact is very limited, particularly when the following are taken into account:

- The restriction of the exceedances to sediments within a relatively narrow creek bed; and,
- The nature of ephemeral creek exposures (the creek is inundated at times; terrestrial receptors would only be potentially exposed for a portion of the year (i.e. when the creek is dry)).

On this basis, it is assessed that omnivorous birds will not source 100% of their diet from the limited area of impact, and the overall exposure concentration will therefore be lower than the maximum concentrations identified. Given the marginal and localised nature of exceedances, the overall exposure concentration for these birds is assessed to be below the screening level, and the risk to omnivorous birds associated with the identified impacts in Mission Creek sediments is assessed to be **low and acceptable**.

[46] **How to read box and whisker plots:** A box and whisker plot shows the full range of the concentrations, together with a visualisation of where most of the concentrations sit. The body of the box and whisker plot ("the box") represents the interquartile range (which is a measure of variability, based on dividing a data set into quartiles). 50% of sample results are within this range. The line in the middle of the box shows the median (middle) value, and the "×" shows the mean (average) value The boxes may have lines extending vertically called "whiskers". These lines indicate variability outside the upper and lower quartiles, and any point outside those lines or whiskers is considered an outlier.

12.9 Risk characterisation: risks to plant health from groundwater

For the purposes of initial screening, the potential risks to plant health associated have been assessed by comparing concentrations in the airport bore to the screening level adopted to assess risks to plant health. This assessment will be conservative for off-airport areas where lower concentrations have been measured or would be expected. The comparison is presented in Table 12-4 below:

Figure 12-10 Comparison of PFAS Concentrations in Groundwater between January 2020 and March 2021

PFOS screening level protective of plant health (µg/L)	PFOS concentration in airport bore (µg/L)	
	January 2020	March 2021
2000	33.1	22.5*

* Duplicate value adopted

The measured concentrations are below the screening level, by approximately two orders of magnitude. The risks to plant health (both on airport, and in off-airport areas) are therefore assessed to be low.

12.10 Terrestrial ecological risk assessment: overall conclusions

Risks to terrestrial ecological receptors have been assessed to be **low and acceptable**, in both on-airport and off-airport areas.

13.0 Aquatic Ecological Risk Assessment

13.1 Problem identification

The aquatic ecosystem is made up of all of the plants and animals that live in the water (as opposed to the terrestrial ecosystem, which includes the plants and animals that live on the land).

Freshwater ecological receptors can be exposed to PFAS impacts in water as follows:

- **Direct exposure:** Species which live in the water (e.g. plants, invertebrates) can be directly exposed to PFAS.
- **Indirect exposure:** PFAS can bioaccumulate within the species which live in the water, and exposure can occur to other wildlife which consume these species as part of their diet (e.g. ducks and other wetland birds).

In the DSI, surface water concentrations were compared with the conservative ecological water quality guideline values for freshwater ecosystems presented in the PFAS NEMP 2.0. On the basis of the identified screening level exceedances, it was recommended that pathways to freshwater aquatic ecological receptors be considered further in the HHERA.

In the DSI, it was concluded that **risks to the marine environment are low**. The marine aquatic ecosystem is therefore not assessed further in this HHERA.

13.2 Identification of assessment areas

13.2.1 Freshwater ecosystems for which further assessment is not required

No surface water was identified on the airport, so the risks to surface water receptors on the airport are assessed to be **low and acceptable**.

PFOS was not detected at concentrations above the limit of reporting (LOR) in the following creeks:

- Rocky Point Creek.
- Broken Bridge Creek up-gradient of the confluence with Cascade Creek.
- Town Creek, up-gradient of the confluence with Watermill Creek.
- An unnamed creek in Broken Bridge catchment, north of Mission Creek (where sample ID007_SPRING was collected).

The risks to freshwater aquatic ecosystems in these creeks is therefore assessed to be **low and acceptable**.

In addition, there are a number of other creeks on island, the catchment areas for which are located away from key source areas. These include Stockyard Creek[47] and water bodies associated with Mount Pitt (with the exception of Broken Bridge Creek). Sampling was not completed in these creeks as part of the DSI because the potential for PFAS from the identified sources to enter these creeks is assessed to be low. The risks to freshwater ecosystems in these creeks associated with PFAS from identified source areas is therefore also assessed to be **low and acceptable**.

[47] The Ball Bay refuelling area was identified as a potential Group 2 (lower risk) source area (PS10). No surface water was identified at this location during Senversa's investigations, and only very low concentrations of PFAS in soil were identified (0.0021 – 0.0024 mg/kg PFOS, below all screening levels). On this basis, the risks to human health and the environment were assessed to be low in this location; no other sources were identified in this catchment.

13.2.2 Areas where further assessment is required

With the exception of those creek systems discussed in Section 13.2.1, PFOS was identified at detectable concentrations in all creek systems sampled in the PSI and DSI.

Table 13-1: PFOS concentrations measured in creeks

Creek	Number of samples	PFOS concentration (µg/L)	
		Min	Max
Mission Creek	13	0.03	44.6
Watermill Creek	13	<0.01	0.29
Cascade Creek[48]	9	<0.01	0.1
Headstone Creek[49]	7	<0.01	0.02

PFOS concentrations in creeks across the island are presented in **Figure 7**. The highest concentrations were measured in Mission Creek. The concentrations in other creeks were much lower (the maximum concentrations outside Mission Creek are more than 100 times lower than in Mission Creek, and generally <0.1 µg/L). On this basis, the main focus of this assessment will be Mission Creek.

However, the conservative screening levels adopted in the DSI for the protection of freshwater ecosystems were very low (e.g. 99% species protection level = 0.00023 µg/L). As such, in all creeks where PFAS is detected (even at low concentrations) further assessment has been undertaken as part of the HHERA. It is emphasised that the screening levels adopted in the DSI are highly conservative, and exceedances of these screening levels do not necessarily indicate risks to the aquatic species present in the creeks on Norfolk Island, simply that further assessment is warranted. On this basis, further assessment of potential risks to freshwater ecosystems in all creeks in which PFAS has been detected (Mission Creek, Watermill Creek, Cascade Creek, Headstone Creek) has been undertaken as part of this HHERA.

13.3 Assessment approach

The assessment has been conducted in accordance with the NEPM framework for ecological risk assessment (ERA), described in **Section 2.2.** The following approach has been followed for this assessment:

- **Receptor identification (Section 13.4):** Potential receptors are described considering the species which may be present in the creeks where PFAS impacts are present, and which could be plausibly exposed to PFAS (via either direct or indirect exposure pathways). The overall sensitivity and environmental values of these areas is also described to provide context regarding the level of protection which is appropriate.
- **Toxicity assessment (Section 13.5):** Screening levels which offer protection to the potential receptors are defined.

[48] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[49] PFAS was only detected within the dam

- **Exposure assessment: (Section 13.6):** Exposure pathways to different receptors are discussed, including discussion of factors which will limit exposure (e.g. localised impacts and limited habitat/food sources). Discussion is also presented regarding the concentrations to which different receptors could be exposed.
- **Risk characterisation (Section 13.7):** PFAS concentrations are compared with the adopted screening levels in order to assess the level of risk to terrestrial ecological receptors.

13.4 Receptor identification

13.4.1 Potential receptors

Section 12.4 presents a detailed discussion of the ecology of Norfolk Island, including details of threatened species identified across island, and the habitats present in areas where PFAS impacts have been identified.

While there is extensive available information regarding the terrestrial ecosystem on Norfolk Island, literature information specifically regarding the species present within the creeks on Norfolk Island is much more limited; this is likely to be a function of the nature of these features. The creeks on island are ephemeral in nature, and many are largely dry other than in times of heavy rain, with only localised pools where water is often or usually present. This will have a major limiting influence on the presence of aquatic species, and certain taxonomic groups will be absent given the nature of the creek systems.

Figure 13-1 to **Figure 13-7** below depict the nature of Mission Creek in different parts of its course, including both sections with and without water present. These figures illustrate the limited presence of water and aquatic habitat in many places, including during periods of flow. Even in a time of high flow, water was only identified in the upper parts of the course of Mission Creek.

Figure 13-1: WWII Dam near the airport; a dam which permanently or usually contains water.

Figure 13-2: Mission Creek at SW21 (during a wet period) showing limited pooled water, and generally bare creek bed.

Figure 13-3: Mission Creek in flow near the airport showing limited water depth and bare creek channel.

Figure 13-4: Pool in Mission Creek (wet period) near the chapel showing limited aquatic habitat in an agricultural paddock.

Figure 13-5: Pool in Mission Creek (dry period) near the chapel showing drought-stressed terrestrial vegetation.

Figure 13-6: Dry bed of Mission Creek near the chapel with terrestrial grass covering dry creek bed (wet period).

Figure 13-7: The end of Mission Creek; the watercourse enters the Pacific Ocean via steep, rocky cliffs with no water found at this location even during a wet period.

Based on the ephemeral nature of the creeks on Norfolk Island, fish are assessed to be absent. Fish can be present in ephemeral creeks. However, unless specialised fish which can survive periods of drought (e.g. lungfish) are present (not the case on Norfolk Island), fish are generally only present in such creeks opportunistically (i.e. swimming into the creek from other water sources during times of flow). Given the absence of continuous identified water in the lower reaches of creeks even during periods of high flow, and the topography where many creeks exit into the ocean over a cliff (Mission Creek depicted as an example in **Figure 13-7**), the opportunistic entry of fish into the creeks on island is not considered plausible. On this basis, **fish are assessed to be absent**.

The following taxonomic groups are assessed to be potentially present within, or dependent on, ephemeral creeks, forming part of the aquatic ecosystem at times when water is present:

- **Aquatic plants:** including algae and micro algae; larger water dependent plants are generally unlikely to be present other than in more permanent pools, given the ephemeral nature of the creeks and the generally shallow nature. It is noted that, many areas of creek bed appear denuded of obvious vegetation (e.g. with visible bare soil both when water is flowing and in dry creek beds). In other locations, grasses and other terrestrial plants are present in creek beds when creeks are dry.
- **Crustaceans:** planktonic crustaceans known to be present within ephemeral creeks include water fleas (such as *Daphnia* and *Moina*) which are free-swimming when water is present, but which can withstand periods of drought (individuals die, but carry resting eggs which remain in dry sediment and hatch when water returns).
- **Insects:** there is a broad insect fauna on Norfolk Island (as discussed in **Section 12.4.2.5**). While the studied species groups are terrestrial in nature, it is considered possible that there are insect species present which are water-dependant for some or all of their lifecycle.
- **Amphibians:** there are no endemic amphibians although individual specimens of introduced species (including the cane toad (*Bufo marinus*) and green tree frog (*Litoria caerulea*)) have been found on island, possibly introduced through cargo shipments. Amphibians are therefore unlikely to be present, but have not been excluded from the assessment.
- **Birds:** in addition to water-dependant aquatic species which may live or spend part of their lifecycle within ephemeral creeks, birds have the potential to form part of the aquatic ecosystem where they consume these aquatic species as part of their diets. **Appendix P** details the birds present on island; of these, the birds assessed to be potentially exposed to surface water impacts via their diet are the waterbirds. Coastal waterbirds (the cormorants) and seabirds have been excluded from this list as their diet is primarily fish or marine invertebrates, and they are unlikely to source their diet from the creeks on island, given the absence of fish (see discussion below). The birds assessed as potentially exposed are summarised below. Most of these birds primarily inhabit more open areas (wetlands, dams and pastures). The purple swamphen *(Porphyrio melanotus)* is known to enter thick vegetation, and is assessed as the bird most likely to be present in the more heavily vegetated parts of the upper reaches of Mission Creek, where the highest PFAS concentrations have been measured.

Table 13-2: Waterbird species identified as most likely to form part of the aquatic ecosystem via consumption of freshwater aquatic species in diet.

Common name	Scientific name	Local name	Native range	Diet
Mallard	*Anas platyrhynchos*		Introduced	Omnivorous (invertebrates and plants)
Pacific Black Duck	*Anas superciliosa*	Duck	Native	Mainly plants, some invertebrates
Feral Goose	*Anser domesticus*		Introduced	Mainly plants (commonly terrestrial species including grass)
White-faced heron	*Egretta novaehollandiae*	Crane	Native	Small aquatic creatures
Purple swamphen	*Porphyrio melanotus*	Tarler bird	Native	Aquatic plants and invertebrates
Spotless crake	*Zapornia tabuensis*	Little tarler bird	Native	Omnivorous and varied (including terrestrial and aquatic species)
Buff-banded rail	*Hypotaenidia philippensis*	Little tarler bird	Native	Omnivorous scavenger, mainly terrestrial diet

Specifically regarding threatened species, these are assessed as **absent from the aquatic creek systems**, as follows:

- Of the threatened species identified on island (see **Section 12.4.1**) none are freshwater aquatic species.
- It is noted that threatened species include endemic land snails, but the only recorded freshwater species *Posticobia norfolkensis* is extinct (DNP, 2010).
- Waterbirds as described above are potentially exposed via diet; none of these species are threatened species.

13.4.2 Site sensitivity and adopted species protection levels

As detailed in the PFAS NEMP 2.0 and in ANZG, the level of protection that should be used to determine the objective for aquatic ecosystems is:

- 99% for high conservation value ecosystems.
  - Effectively unmodified or other highly valued ecosystems, typically (but not always) occurring in national parks and conservation reserves, or in remote and inaccessible locations.
- 95% for slightly to moderately disturbed ecosystems.
  - Ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity. The biological communities remain in a healthy condition and ecosystem integrity is largely retained.
  - Freshwater systems would typically have slightly to moderately cleared catchments or reasonably intact riparian vegetation. For example, rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism.
- 90% for highly disturbed ecosystems.
  - Measurably degraded ecosystems of lower ecological value. For example, shipping ports and sections of harbours serving coastal cities, urban streams receiving road and stormwater runoff, or rural streams receiving runoff from intensive horticulture.

The above protection levels are relevant for assessment of direct toxicity to aquatic organisms. In accordance with ANZG recommendations, the next higher protection level should be adopted for assessment of potential bioaccumulative / secondary poisoning effects where site-specific data on bioaccumulation is not available (e.g. the 99% level for slightly to moderately disturbed ecosystems).

Norfolk Island does not have defined areas designating status of aquatic ecosystems in each catchment. However, based on ANZG descriptors above describing the level of protection afforded to a water body based on its ecosystem conditions, all of the creeks forming part of this assessment have been assessed as “slightly to moderately disturbed”. This is considered a conservative designation for some creeks in some areas given, for example, the absence of riparian vegetation in many of the areas of the creeks used most extensively for cattle grazing (see e.g. **Figure 13-7**).

The overall protection category and adopted species protection levels for these creek systems are summarised below, although it is noted that, where relevant, the species protection levels for highly disturbed ecosystems (90% for direct toxicity and 95% for bioaccumulation) will also be considered for comparative context in the assessment.

Table 13-3: Adopted species protection levels

Protection category	Creek	Species protection level (direct toxicity)	Species protection level (bioaccumulation)
Slightly to moderately disturbed	Upper Mission Creek	95%	99%
	Lower Mission Creek		
	Watermill Creek		
	Cascade Creek / Cockpit Weir		
	Headstone Creek		

13.5 Toxicity assessment

The ecological water quality guideline values presented in the PFAS NEMP 2.0 were derived by ANZG[50]. These values have been reviewed to determine if adjustment to the default screening levels is warranted on a site-specific basis, based on the potential receptors present.

The default ecological water quality guideline values were derived using a Species Sensitivity Distribution (SSD) approach. Briefly, this consists of graphing the chronic (i.e. long-term) No Observed Effect Concentration (NOEC) of the particular toxicant against the percentage of species that are potentially affected. From this graph, it can then be determined at what concentration a given number of species are protected. An example of an SSD graph is included in **Figure 13-8** below.

The toxicity data used in the ANZG derivation was extracted and taxonomic groups that were not known to be found within on-island creeks were removed from the analysis. Specifically, fish were removed from the dataset. This data is presented in **Appendix R**.

This dataset was run through the statistical program Burrlioz (version 2.0, CSIRO). The Burrlioz report, is presented in **Appendix R.**

The species sensitivity distribution output by Burrlioz is shown in **Figure 13-8.**

[50] ANZG, 2015. Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Toxicant Guideline Values – PFOS (Freshwater)

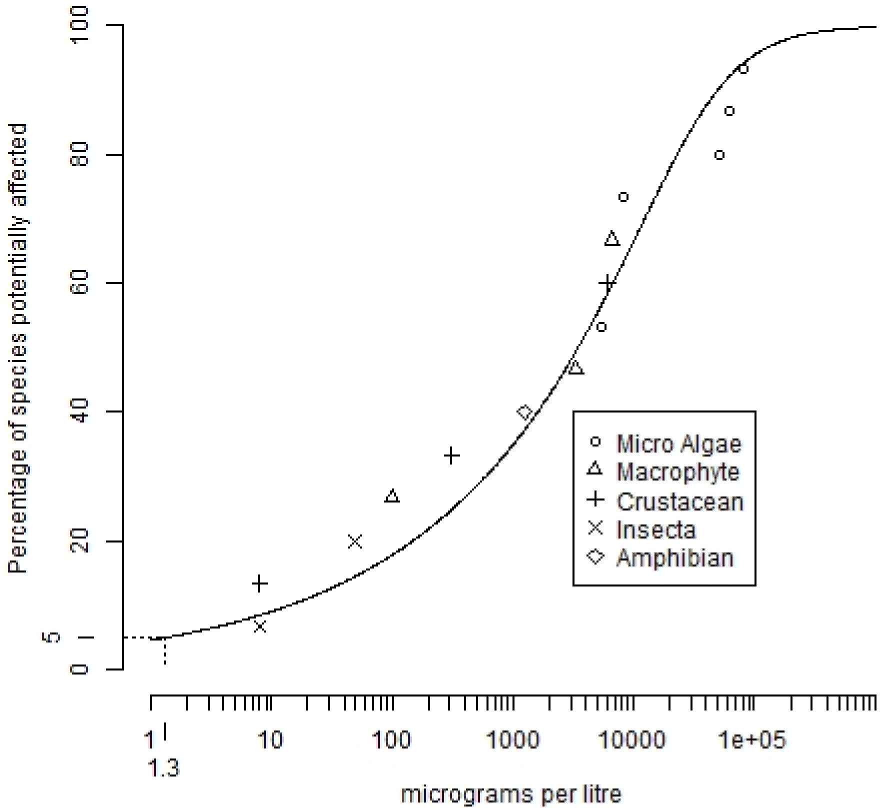


Figure 13-8: SSD[51] for PFOS in freshwater (based on ANZG, 2015 dataset excluding fish) showing the 95% species protection value (1.3 µg/L).

The calculated 99%, 95% and 90% species protection limits based on this revised SSD are included in Table 13-4below.

Table 13-4: Refined PFOS screening levels

Species protection level (%)	PFOS screening level (µg/L)
99%	0.0055
95%	1.3
90%	14

[51] The x-axis indicates the PFOS concentration at which there was no observed effect on the listed species. The y-axis shows the percentage of species that are potentially affected. A 95% protection limit is calculated by intercepting the line at the 5% value on the y-axis. The corresponding value on the x-axis is the 95% protection guideline value.

13.6 Exposure assessment

Freshwater ecological receptors can be exposed to PFAS impacts in water as follows:

- **Direct exposure:** Species which live in the water (e.g. plants, invertebrates) can be directly exposed to PFAS.
- **Indirect exposure:** PFAS can bioaccumulate within the species which live in the water, and exposure can occur to other wildlife which consume these species as part of their diet (i.e. the ducks and other wetland birds outlined in **Table 13-2**).

The relevant exposure concentrations for the direct exposure assessment are the water concentrations to which aquatic species would be exposed (i.e. the measured creek concentrations outlined in **Table 13-1**).

Indirect exposure pathways (i.e. bioaccumulation pathways) have also been assessed through comparison of the creek concentrations with water screening levels. This screening level approach does not directly consider the PFAS concentrations in creek biota which could be consumed by birds, and has been adopted because sampling of aquatic biota has not currently been undertaken, and because of the inherent uncertainties associated in estimating biota concentrations from water concentrations.

13.7 Risk characterisation

13.7.1 Direct exposure

Potential risks to aquatic species which might live within the water of the creeks on-island have been assessed through comparison of measured creek concentrations to the screening value for direct toxicity. For the purposes of initial screening, the 95% species protection value (1.3 µg/L PFOS) is adopted, as this is the screening value applicable for slightly-moderately disturbed ecosystems:

Table 13-5: Comparison of PFOS concentrations measured in creeks to direct toxicity screening levels

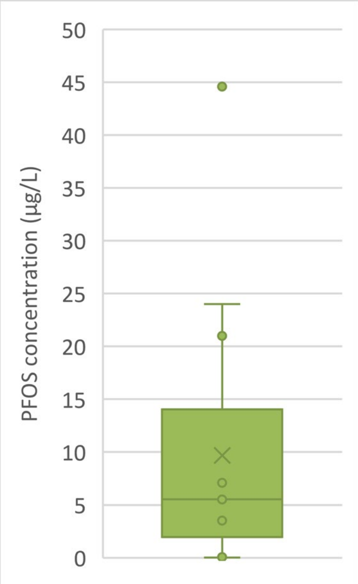
Creek	PFOS concentration (µg/L)		
	Screening level for direct toxicity	Min	Max
Mission Creek	1.3	0.03	**44.6**
Watermill Creek		<0.01	0.29
Cascade Creek[52]		<0.01	0.1
Headstone Creek[53]		<0.01	0.02

PFOS concentrations in creeks across the island are presented in **Figure 7**. For Watermill Creek, Cascade Creek and Headstone Creek, the concentrations are all below the adopted direct toxicity screening level. The risks via direct water exposure to aquatic species living in these creeks are therefore assessed to be **low and acceptable**.

[52] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[53] PFAS was only detected within the dam

The maximum concentrations in Mission Creek exceed the screening level, indicating potentially elevated exposures to aquatic species in this creek system. The range in concentrations are presented on the box plot[54] below:

Figure 13-9: Box plot showing the range in PFOS concentrations in water sampled from Mission Creek



It can be seen from this box plot that almost all of the concentrations exceed the screening level for direct toxicity applicable for slightly-moderately disturbed ecosystems (1.3 µg/L)

As discussed in **Section 13.4.2**, designation of Mission Creek as "slightly to moderately disturbed" may be conservative for parts of the creek given the absence of riparian vegetation in the areas used most extensively for cattle grazing. The majority of the concentrations also exceed the screening level for direct toxicity applicable for highly disturbed ecosystems (14 µg/L), indicating potential risks even if a lower protection category applies. Furthermore, the upper parts of Mission Creek (where the highest concentrations are measured) are located away from agricultural disturbance.

Overall, it is concluded that the risks to aquatic species via direct exposure in Mission Creek are **potentially elevated.**

Overall, it is concluded that while risks via direct water exposure to aquatic species living in other creeks are low and acceptable, risks within Mission Creek are **potentially elevated**.

13.7.2 Indirect exposure (bioaccumulation)

Potential risks to birds which might consume aquatic species as part of their diet have been assessed through comparison of measured creek concentrations to the screening value for indirect toxicity. For the purposes of initial screening, the 99% species protection value (0.0055 µg/L PFOS) is adopted, as this is the screening value applicable for slightly-moderately disturbed ecosystems:

[54] **How to read box and whisker plots:** A box and whisker plot shows the full range of the concentrations, together with a visualisation of where most of the concentrations sit. The body of the box and whisker plot ("the box") represents the interquartile range (which is a measure of variability, based on dividing a data set into quartiles). 50% of sample results are within this range. The line in the middle of the box shows the median (middle) value, and the "×" shows the mean (average) value The boxes may have lines extending vertically called "whiskers". These lines indicate variability outside the upper and lower quartiles, and any point outside those lines or whiskers is considered an outlier.

Table 13-6: Comparison of PFOS concentrations measured in creeks to direct toxicity screening levels

Creek	PFOS concentration (µg/L)		
	Screening level for direct toxicity	Min	Max
Mission Creek	0.0055	0.03	**44.6**
Watermill Creek		<0.01	**0.29**
Cascade Creek[55]		<0.01	**0.1**
Headstone Creek[56]		<0.01	**0.02**

PFOS concentrations in creeks across the island are presented in **Figure 6**.

The maximum concentrations in all creek systems exceed the screening level, indicating potentially elevated exposures to birds which may consume aquatic species as part of their diet.

As discussed in **Section 13.4.2**, designation as "slightly to moderately disturbed" may be a conservative designation for some creeks in some areas given, for example, the absence of riparian vegetation in many of the areas of the creeks used most extensively for cattle grazing. However, the following are noted:

- **Mission Creek:** the majority of the concentrations also exceed the screening level for indirect toxicity applicable for highly disturbed ecosystems (1.3 µg/L), indicating potential risks even if a lower protection category applies. Furthermore, the upper parts of Mission Creek (where the highest concentrations are measured) are located away from agricultural disturbance.
- **Other Creeks:** while concentrations are below the indirect toxicity screening level for highly disturbed systems (1.3 µg/L), it is noted that there are many locations along these creeks where disturbance is not present, and designation of the creeks as highly disturbed is not considered to apply. In particular, it is noted that where Watermill Creek passes through Kingston Common, fencing has been erected to limit cattle access to the creek, with the aim of reducing creek disturbance and improving creek condition. In this area, indirect toxicity screening level for slightly-moderately disturbed ecosystems (0.0055 µg/L PFOS) is applicable, and the PFOS concentrations in this area (0.03 – 0.04 µg/L) are elevated above this screening level.

Overall, it is assessed that concentrations in all creeks exceed the applicable screening level or the protection of birds which may consume aquatic species as part of their diet. It is, however, emphasised that this screening assessment is conservative in nature. The potential for birds to be exposed to the aquatic biota within these creeks will be limited by the ephemeral nature of the creeks, including the presence of limited water / aquatic habitat even at times of flow. This will:

- Reduce the potential for the creeks to provide habitat for species which could form part of the diet of birds;
- Reduce the size of the aquatic habitat from which birds could source their diet; and,
- Limit the times of the year where aquatic species would be present to form part of the diet of birds.

[55] including Cockpit weir, down-gradient of the confluence with Broken Bridge Creek
[56] PFAS was only detected within the dam

On this basis, there is reduced potential for birds to source their diet form these creeks. However, given the of some of the identified exceedances (for example, the highest concentration measured in Mission Creek (44.6 µg/L PFOS) is nearly 10,000 times above the adopted screening level (0.0055 µg/L)), the potential for elevated exposure cannot be entirely excluded and on the basis of this screening assessment, the potential risks to birds which may consume aquatic species as part of their diet are assessed to be potentially elevated.

13.7.3 Limitations and requirement for further assessment and/or management

The screening assessment has indicated the following:

- **Direct toxicity:**
  - There are **potentially elevated** risks to aquatic biota within Mission Creek which are directly exposed to PFAS impacts in water;
  - Risks are assessed to be **low and acceptable** for aquatic biota within other creeks which are directly exposed to PFAS impacts in water.
- **Indirect toxicity (bioaccumulation):**
  - Potential risks to birds which may consume aquatic species as part of their diet is assessed to be **potentially elevated**.

On this basis further assessment and/or management is required. These works should be undertaken as part of the PFAS Management Plan.

14.0 Risk assessment uncertainties

Uncertainties and limitations associated with the assessment have been highlighted throughout the report, and the conclusions drawn have taken into account these uncertainties. Key uncertainties and limitations have been summarised in the sections below.

14.1 Temporal variability in concentrations

This HHERA is based on the concentrations measured at the time of the PSI and DSI completed by Senversa. It is noted that there is insufficient data to fully establish trends in concentrations. Further monitoring is therefore required to assess how concentrations may change in the future. Changes in concentration could result in changes to the risk profile, and may require a review of the risk assessment presented here.

14.2 Land use

The HHERA has considered the range of land uses identified at the time of the PSI and DSI sampling works. Should land uses vary from those identified, the conclusions of the report may change. There is discussion regarding the potential impact of land use changes on the results of the assessment in Section 11.5.

14.3 Continuation of management measures

There were a number of pathways for which the DSI assessed risks to be effectively managed through the use of existing management measures (e.g. advisory notices on water use, provision of alternate water supplies); these pathways have not been further assessed in the HHERA. The assessment of low risk via these pathways is therefore contingent on the continued use of management measures. A summary of management measures in place at the time of the DSI is provided in **Section 1.4.2**.

14.4 Key pathway-specific uncertainties

Blood serum (or blood plasma) data in livestock has not been collected. It was therefore necessary to estimate the concentrations in blood serum (or blood plasma), from the likely intake from stock water. There are uncertainties associated with this estimation. These uncertainties relate both to the behaviour of PFAS (i.e. what concentration in cattle might be expected for a given exposure), and also in estimating the level of exposure where cattle may move around and be exposed to different concentrations over time. A generally conservative approach has been adopted in the risk assessment, whereby it is assumed cattle could be continuously exposed to the maximum stock watering concentrations identified, resulting in steady-state conditions being reached. This approach will be conservative for cattle which are not continuously exposed to PFAS.

The screening levels for a number of consumption pathways (e.g. livestock, produce irrigation) have been derived separately for PFOS and PFHxS, given the potential for uptake into livestock is very different for these two PFAS. As such, they do not account for potential cumulative exposures to PFOS and PFHxS. Notwithstanding this limitation, given the high degree of conservatism in the screening levels (as highlighted through the report), they are considered appropriate and protective, and provided individual concentrations remain below the concentrations, risks are assessed to be low and acceptable, and further investigation is not warranted.

Specifically, it is noted that limited grass data is available; notwithstanding this it is still concluded that a pathway of consumption of PFAS-impacted grass by cattle is unlikely to be significant. The uncertainties associated with the limited grass data, and the impact on the overall conclusions is discussed in **Section 5.8.4**. In this context, limitations in the grass assessment are summarised below:

- The separately derived screening levels for stock water and grass (for livestock) do not account for potentially cumulative exposures from both stock watering and grass. It is noted that cumulative exposure via these pathways is unlikely, given the very localised grass impacts present on-island (i.e. limited to the creek bed of Mission Creek). For cattle on paddocks with access to Mission Creek, at times of creek flow, cattle will have access to Mission Creek water as drinking water, but grass would not be present within the creek bed at these times. When the creek is dry, grass could be consumed, but there will not be access to creek water for drinking. As such, exposure via grass and creek water are unlikely to occur simultaneously.
- While the incidental ingestion of soil during grass consumption cannot be excluded, this pathway has not been quantitatively accounted for in the derivation of the grass screening levels. PFAS exposure via grass will be much more significant than via soil given the much greater volumes of grass consumed when compared with soil; given the overall conservative nature of the assessment consideration of grass alone is assessed as conservative to account for the total exposure which could occur via both pathways. Furthermore, given the very localised nature of soil impacts to which livestock have access (restricted to the sediments in dry creek beds) this pathway is unlikely to be a significant source of PFAS exposure in livestock.

15.0 Conclusions and Recommendations

15.1 Pathways assessed to pose negligible risk

For the following pathways, risks are assessed to be negligible, and further assessment is not required:

Livestock

- Home consumption or public consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment.
- Home consumption of public consumption of cattle products, where cattle are fed with grass cut from the airport.
- Livestock health (across the island)

Consumers of produce (fruit and vegetables)

- Consumption of home produce (fruit/vegetables) grown within the Mission Creek catchment (at the one property where this currently occurs).
- Consumption of home produce (fruit/vegetables) grown outside the Mission Creek catchment.

Consumers of chicken eggs

- Consumption of chicken eggs where chickens drink water sourced from outside Mission Creek catchment.

Firefighters

- Systems testing, training and firefighting activities completed by firefighters using water sourced from the Airport Bore.

On-airport workers

- Incidential soil and dust exposure by intrusive workers.
- Incidental soil and dist exposure by airport workers.

Off-site residents (e.g. farmers) or recreational users of creeks

- Incidental contact with surface water in creeks during work or recreation.

Terrestrial ecological receptors

- Exposure to PFAS impacted soil, groundwater and sediments (while creeks are dry), or via bioaccumulation of PFAS through the food web.

Aquatic ecological receptors

- Direct exposure of aquatic species to water in creeks other than Mission Creek.
- Risks to the marine environment (both direct and indirect exposure) are also assessed to be negligible (in accordance with the conclusions of the DSI).

15.2 Pathways for which further assessment or management required

Livestock

- Home consumption or public consumption of cattle products where cattle drink water sourced from Mission Creek.
  - Risks to public consumers are assessed to be generally **low and acceptable**. Nonetheless, there are a number of uncertainties in the assessment, and therefore further assessment and/or management is recommended.
  - It is emphasised that there are no regulatory restrictions with respect to PFAS in livestock products (including cattle products) and that, currently, there are no regulated maximum limits for PFAS in any foods in Australia or overseas but research is ongoing.

Consumers of chicken eggs

- Consumption of chicken eggs where chickens drink water sourced from Mission Creek.
  - Risks are low and acceptable based on the limited available data. Given the uncertainties associated with the limited data set, further assessment and/or management is recommended.

Aquatic ecological receptors

- Direct exposure of aquatic species to water in Mission Creek.
- Indirect exposure to birds which may consume aquatic species as part of their diet (both in Mission Creek and other creeks).

A PFAS Management Plan will be developed which details the strategy for managing the risks associated with the identified PFAS impacts on the airport and across the island. The PFAS Management Plan should develop specific strategies for further assessment and/or management of the pathways detailed above.

15.3 Data Gaps

The HHERA has identified a number of areas where risks are unlikely to be elevated, but additional data is required to confirm potential risks:

15.3.1 Grass concentrations in Mission Creek

While the risks to consumers of produce where the cattle have access to grass within Mission Creek are assessed to be low and acceptable, it is acknowledged that the available data regarding PFAS in grass within the Mission Creek bed is very limited, and that further sampling would therefore support the assessment.

As discussed in **Section 5.9** below, further assessment and/or management of the stock watering pathway for cattle which may access water within Mission Creek is assessed to be required. The requirement for further assessment/management of this pathway should be further assessed as part of the PFAS Management Plan.

15.3.2 Assessment of risk to consumers of pork products

There is limited literature data on which to estimate screening levels for pigs. On this basis, when coupled with the limited information regarding where pigs might be kept and stock watering sources for these animals, further assessment has not been undertaken at this stage. The following are noted:

- Water and Land use surveys have not provided any indication that pigs are kept in the Mission Creek catchment. This pathway is assessed as inactive.
- Risks from consumption of livestock products where livestock drink water sourced from outside Mission Creek catchment are assessed to be low and acceptable (based on comparison to screening levels which assume high consumption rates). As noted in **Section 5.4.5**, the keeping of pigs is limited on island and consumption rates are likely to be generally lower than other livestock product types. On this basis, it is unlikely that elevated risks would be associated with the consumption of pork and other pig products where pigs drink water sourced from outside Mission Creek catchment. Notwithstanding this, risks cannot be fully excluded without additional information and/or assessment.

This is noted as a data gap; the requirement for further assessment/management of this pathway should be further assessed as part of the PFAS Management Plan.

15.4 Future changes in conditions

The HHERA assesses the current risks associated with the currently identified concentrations of PFAS in the environment; and the current ways in which exposure occurs.

There is insufficient data to fully establish trends in water concentrations. Further monitoring should be conducted as part of the PFAS Management Plan to determine the long-term trend in water concentrations. The PFAS Management Plan should also detail the strategy for assessing ongoing monitoring results, noting that changes in concentration could result in changes to the risk profile presented in this HHERA.

In addition, it is noted that the HHERA is based on the current land uses at the time of the PSI and DSI completed by Senversa. If land uses were to change in the future, it is noted that the risk profile may change. The PFAS Management Plan should therefore also detail the strategy for assessing changes to the risk profile in the event of future land use changes.

16.0 Principles and Limitations of Investigation

This document was prepared to meet the objectives outlined in this report. Environmental reports and health risk assessments are typically based on a limited set of data. Additional sampling and information may improve the confidence or yield different results, due to a range of factors such as the variable or heterogeneous nature of environmental contaminants in the subsurface. Care should be taken, and no warranty is provided, in the application of any costs or contingent liabilities derived using the data or conclusions within this report.

The assessment is based on a review of previous reports and data relating to the condition of the site, and the current understanding of land uses as summarised in relevant sections of the report. Senversa’s conclusions presented in this report are therefore based on the information available during the assessment and the assumptions made based on this information. Reasonable care has been taken to avoid reliance upon data and information that may be inaccurate, however different conclusions may be reached if additional information becomes available or if assumptions stated in the report are found to be violated.

The health risk assessment process and derivation of health-based and ecological screening levels involves a number of assumptions regarding site conditions, human exposure, wildlife exposure and chemical toxicity. It is not always possible to fully predict or describe site conditions, human activities and ecological activities. There are also uncertainties and lack of existing scientific knowledge regarding the behaviour, fate and transport (including uptake and bioaccumulation) of PFAS in the environment. A number of the key uncertainties are discussed in **Section 14.0**. The assumptions adopted for this risk assessment were therefore generally selected to be conservative in nature, in order to evaluate an assumed reasonable maximum exposure scenario and provide a deliberate margin of safety.

It is also noted that PFAS are emerging contaminants for which scientific knowledge and regulatory guidance is rapidly evolving. The conclusions of this HHRA may therefore be subject to change as new scientific information and guidance becomes available.

This document has been prepared for the use of DITRDC and the appointed environmental auditor. The scope of work performed may not be appropriate to satisfy the needs of any other person. Any other person’s use of, or reliance on, the findings, conclusions, recommendations or any other material presented herein, is at that person’s sole risk.

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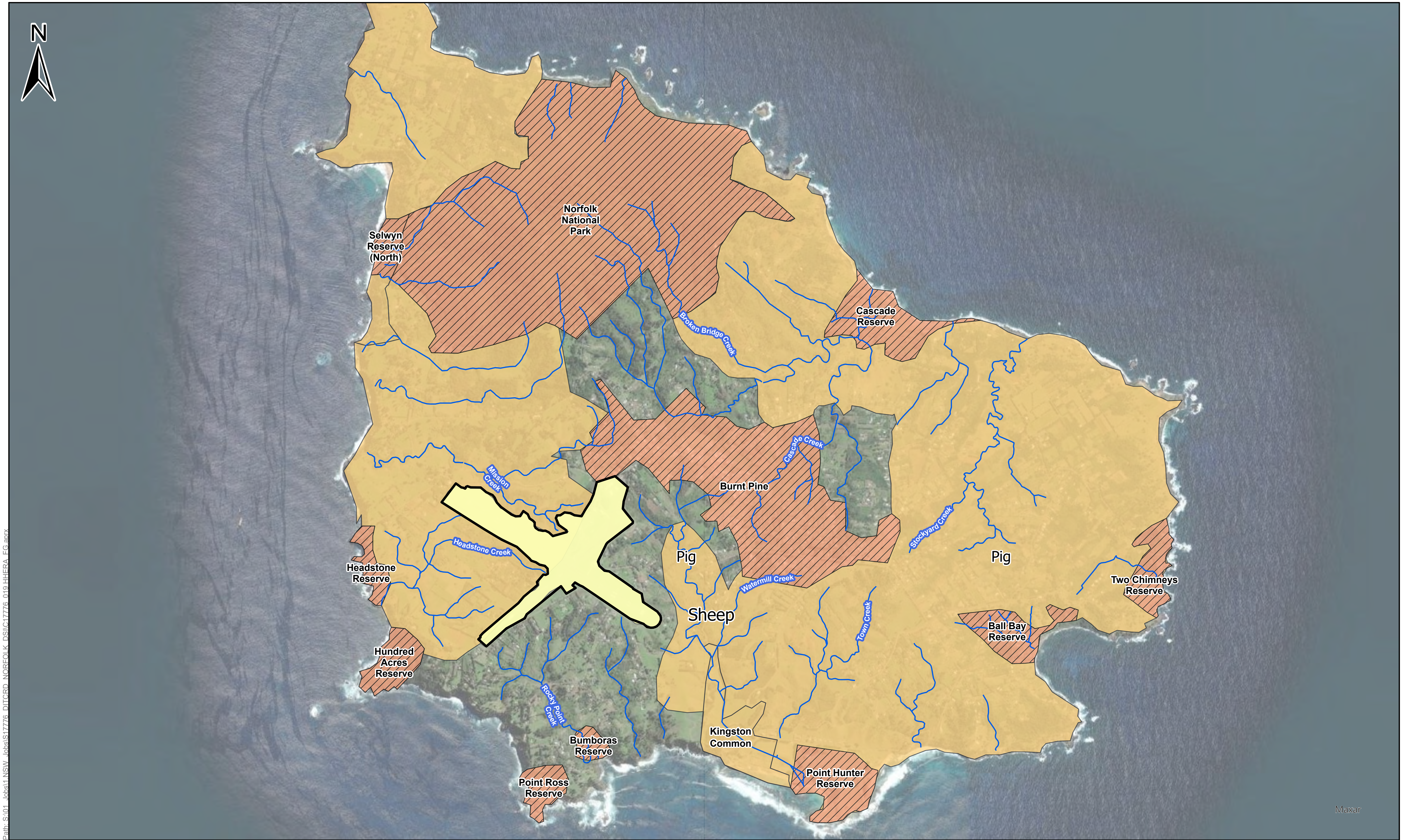
Figures



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Legend:

Land Use

- No Grazing
- Cattle Grazing
- Airport
- Creek

Details:

Data Sources:
Aerial imagery: Esri maps
Vector Datasets: Open Street Maps

Created: F. Gurnett
PM: C. Sandiford
Approved: x
Date: 18/10/2021
Revision: 0

0 1,000 2,000 3,000 Metres

Datum/Projection: WGS 1984 Web Mercator Auxiliary Sphere Scale: 1:35,000(A3)

Figure No: 1

Title: **Livestock Grazing and Distribution**

Project: HHERA

Location: Norfolk Island International Airport

Client: Department for Infrastructure, Transport, Regional Development and Communications

Legend:
- Surface Water Sample Locations
- Creek
- Approximate Airport Boundary

Sample I.D
PFOS (µg/L)
PFHxS (µg/L)
*QC Result Adopted

Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created: F. Gurnett
PM: C. Sandiford
Approved: x
Date: 20/10/2021
Revision: 0

0 500 1,000 1,500 Metres

Datum/Projection:WGS 1984 Web Mercator Auxiliary Sphere Scale:1:25,000(A3)

Figure No: 2

Title: **Surface Water Concentrations – PFOS and PFHxS**

Project: HHERA

Location: Norfolk Island International Airport

Client: Department for Infrastructure, Transport, Regional Development and Communications

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Path: S:\01_Jobs\1_NSW_Jobs\S17776_DITCRD_NORFOLK_DSI\C17776_019 HHERA_FG.aprx

Last Edited by: fidelma.gurnett

Legend:
- Soil Samples
- Creek

Sample I.D
PFOS (mg/kg)
*QC Result Adopted

senversa

Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created: F. Gurnett
PM: C. Sandiford
Approved: -
Date: 22/09/2021
Revision: 0

0 10 20 30 Metres

Datum/Projection: WGS 1984 Web Mercator Auxiliary Sphere Scale 1:1,000 (A3)

Figure No: 3

Title: **Distribution of PFOS concentrations in soil at the works depot**

Project: HHERA

Location: Norfolk Island Airport

Client: Department for Infrastructure, Transport, Regional Development and Communications

Last Edited by: fidelma.gurnett

Path: S:\01_Jobs\1.NSW_Jobs\S17776_DITCRD_NORFOLK_DSI\C17776_019_HHERA_FG.aprx

Legend:

- Soil Samples

Sample I.D
PFOS (mg/kg)
PFAS NEMP 2.0: Ecological, indirect exposure

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Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created:	F. Gurnett
PM:	C. Sandiford
Approved:	-
Date:	22/09/2021
Revision:	0

0 10 20 30 Metres

Datum/Projection:WGS 1984 Web Mercator Auxiliary Sphere Scale1:850 (A3)

Figure No:	**4**
Title:	**Distribution of PFOS concentrations in soil at private property ID_013**
Project:	HHERA
Location:	Norfolk Island Airport
Client:	Department for Infrastructure, Transport, Regional Development and Communications

Last Edited by: fidelma.gurnett

Path: S:\01_Jobs\1_NSW_Jobs\S17776_DITCRD_NORFOLK_DSI\C17776_019_HHERA_FG.aprx

Legend:

- PFOS concentration exceeds screening level for herbivorous birds
- PFOS concentration exceeds screening level for omnivorous bird
- Soil sampling location with no exceedances

Sample I.D

Ecological screening level for herbivorous birds: 5.1 mg/kg PFOS

Ecological screening level for omnivorous birds: 0.33 mg/kg PFOS

*QC Result Adopted

Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created:	F. Gurnett
PM:	C. Sandiford
Approved:	-
Date:	1/11/2021
Revision:	0

0 150 300 450 Metres

Datum/Projection: WGS 1984 Web Mercator Auxiliary Sphere Scale 1:7,500 (A3)

Figure No:	**5**
Title:	**Exceedances of site-specific terrestrial ecological screening levels in on-airport - soil and sediment**
Project:	HHERA
Location:	Norfolk Island Airport
Client:	Department for Infrastructure, Transport, Regional Development and Communications

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Legend:

PFOS (mk/kg)

- No Exceedance
- PFOS Exceedance

Sample I.D
PFOS Exceedance criteria (mg/kg) 0.33

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Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created: F. Gurnett
PM: C. Sandiford
Approved: x
Date: 22/09/2021
Revision: 0

0 200 400 600 Metres

Datum/Projection: Scale: (A3) 1:8,500

Figure No: 6

Title: Exceedances of screening level for omnivorous birds in Mission Creek - sediments

Project: HHERA

Location: Norfolk Island International Airport

Client: Department for Infrastructure, Transport, Regional Development and Communications

Last Edited by: fidelma.gurnett

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Legend:
- Surface Water Sample Locations
- Creek
- Approximate Airport Boundary

Sample I.D
PFOS (µg/L)

Details:

Data Sources:
Aerial imagery: Nearmap Pty Ltd
Vector Datasets: Open Street Maps

Created: S. Koroblitsas
PM: C. Sandiford
Approved: x
Date: 22/09/2021
Revision: 0

0 530 1,100 1,600 Metres

Datum/Projection:WGS 1984 Web Mercator Auxiliary Sphere Scale: 1:26,000(A3)

Figure No: 7

Title: **Surface Water Concentrations (PFOS)**

Project: HHERA

Location: Norfolk Island International Airport

Client: Department for Infrastructure, Transport, Regional Development and Communications

Last Edited by: fidelma.gurnett